NASA CR-66875

THE IMPACT OF VEHICLE LEAKAGE ON THE AILSS

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November 1969

Prepared Under Contract No. NAS 1-7905 by

HAMILTON STANDARD

DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONN.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWARD

This report has been prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Langley Research Center, in accordance with Contract NAS 1-7905. The report describes additional work accomplished upon completion of the AILSS Final Report (Trade-off Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems).

Appreciation is expressed to the technical monitors, Mr. W.D. Hypes and Mr. F.W. Booth, of NASA-Langley Research Center, for their advice and guidance.

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INTRODUCTION

The Advanced Integrated Life Support System (AILSS) was based on the assumption that 1980 design and fabrication techniques will reduce vehicle cabin leakage to a rate of one pound per day. Nevertheless, consideration of higher leakage rates would broaden the scope and usefulness of the AILSS study. Accordingly, this supplementary study discusses the influence of cabin leakage on the AILSS.

Leakage rate obviously affects the oxygen and nitrogen storage system, which is designed to provide gas for cabin leakage makeup as well for repressurization. Leakage also has a strong influence on the oxygen generation subsystem, where variations of the Sabatier process become attractive, and on the water management subsystem, where closed cycle air evaporation becomes a more serious competitor. The influence of leakage on the atmospheric contamination control system must also be studied. Leakage would appear unrelated to waste control, but generation of oxygen by electrolysis of water recovered from food wastes may be valuable. Other EC/LS subsystems are not greatly influenced by leakage rate.

The influence of leakage on oxygen generation is most complex, because hydrogen obtained from decomposition of oxygen or nitrogen-containing chemicals may be used in a Sabatier reactor for carbon dioxide reduction. This necessitates expanding the scope of the AILSS oxygen generation tradeoff to include generation of oxygen and nitrogen for leakage makeup. Because oxygen generation is the only AILSS area where leakage rate has a drastic impact on concept selection, it is considered at greater length than other topics in this discussion. This subject is also of particular interest, because some of the alternatives described may form the basis for earlier life support systems.

Conclusions regarding subsystem selection are indicated in figure 1, which shows the influence of leakage rate on AILSS concept selections. Here and throughout this report, "leakage rate" denotes total vehicle leakage to space, including both oxygen and nitrogen. In general, the leakage range considered is sufficient to determine the equivalent weight impact for any reasonable leakage rate.

The AILSS schematic, which forms the basis for this study, is shown in figure 2.

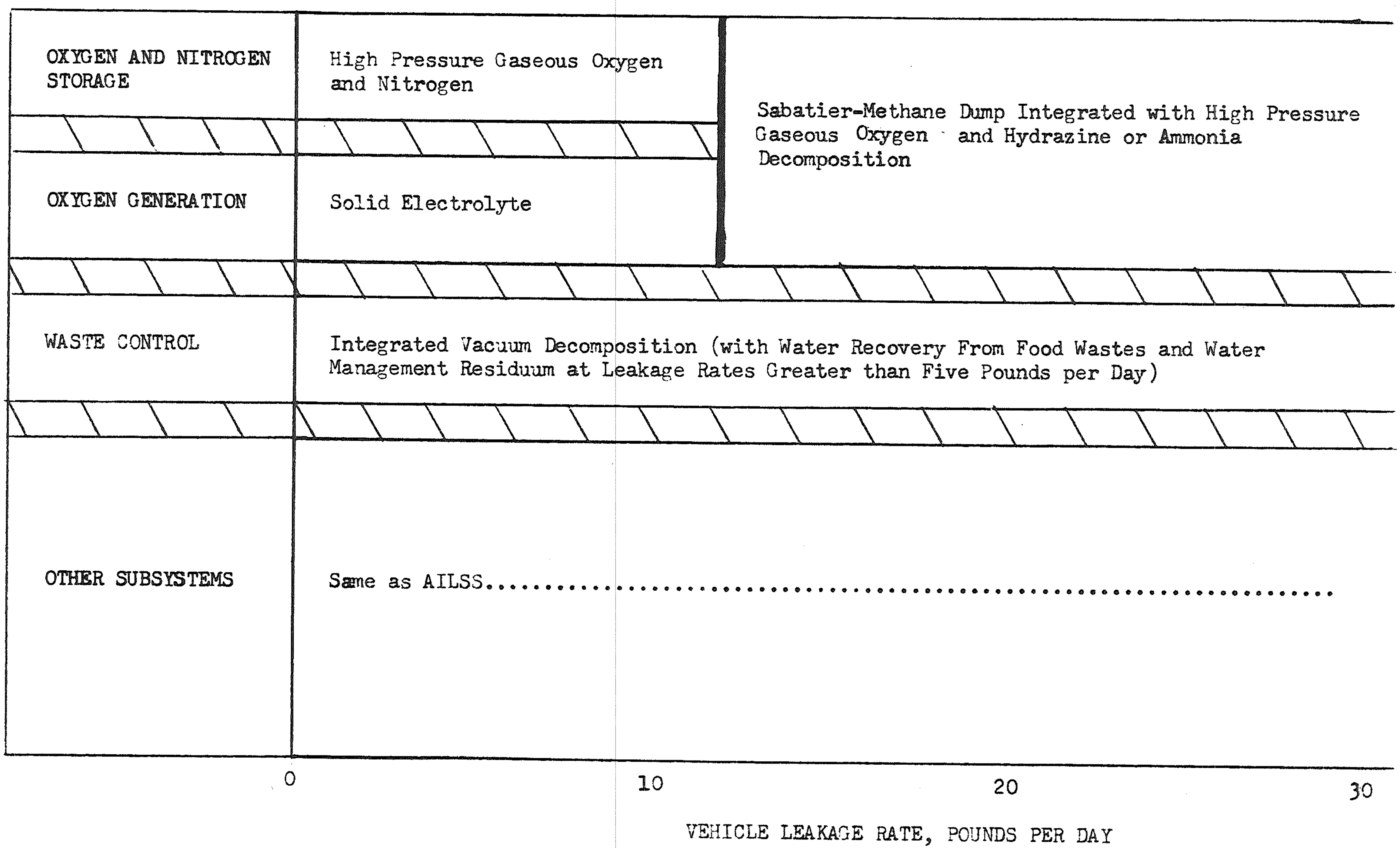

Figure 1. - Influence of Leakage Rate on AILSS Concept Selection

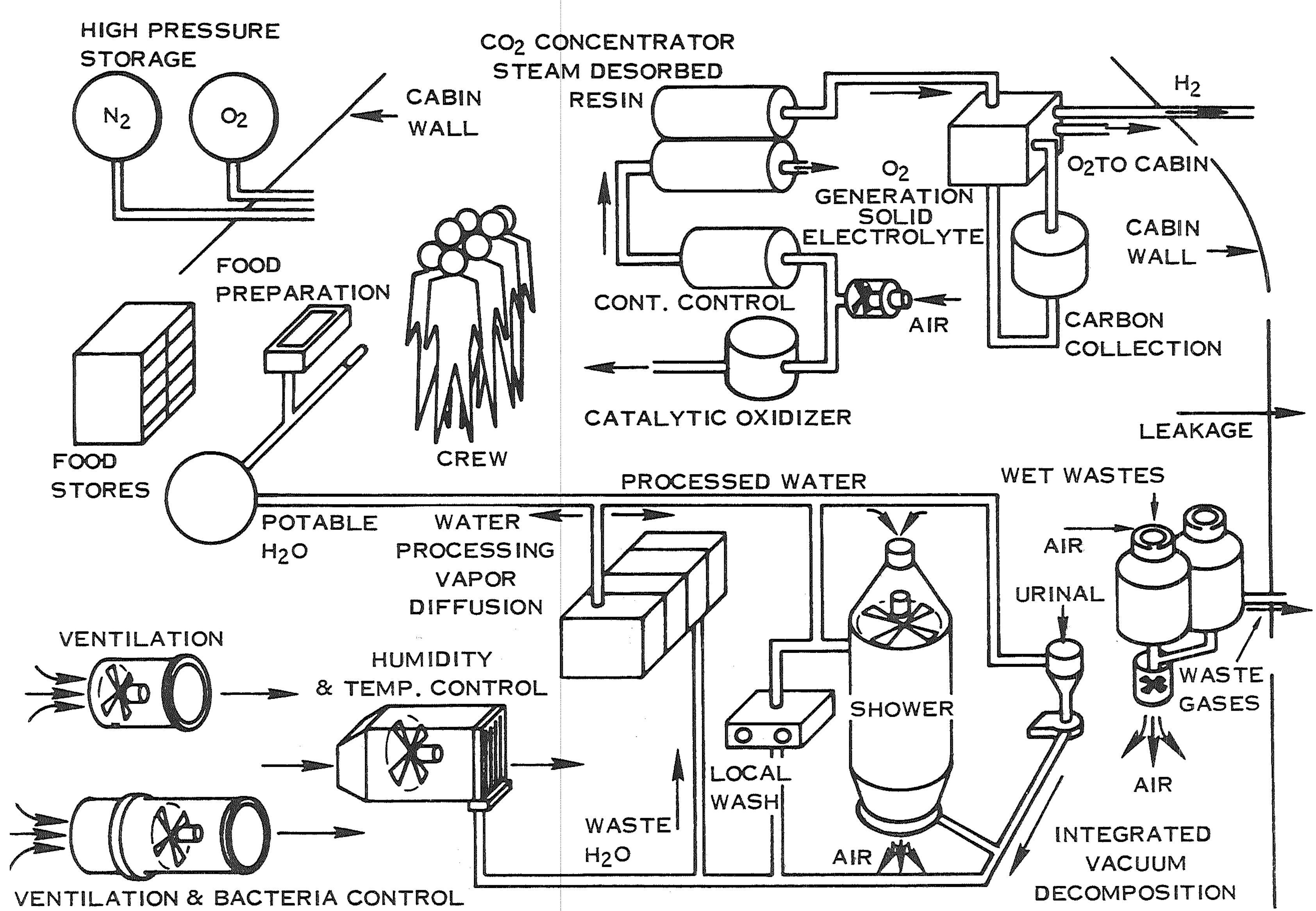

Figure 2. Advanced Integrated Life Support System

OXYGEN AND NITROGEN STORAGE

In the AILSS, where leakage makeup is supplied solely from stored gases because oxygen leakage is much lower than oxygen metabolic consumption, vehicle leakage increases affect oxygen and nitrogen storage more directly than any other subsystem. Oxygen and nitrogen quantities for leakage makeup are directly proportional to the leakage rate. Moreover, the weight of the high-pressure, filament-wound storage tanks is also proportional to leakage rate (as well as mission duration), because tank size is limited by the stress level, and more leakage means more tanks. The effect of leakage rate on weight of the oxygen and nitrogen storage subsystem is shown in figure 3. This conclusion, however, applies to an independent leakage makeup system.

When leakage makeup gas requirements are integrated with metabolic oxygen supply requirements, decomposition of stored chemicals to supply oxygen and nitrogen may be used instead of stored, gaseous oxygen and nitrogen. This possibility is considered later, in the oxygen generation section of this report. In the AILSS study, subcritical and supercritical cryogenic storage competed most closely with high pressure storage. With increasing leakage rate, the relative equivalent weights of these concepts do not change significantly, and so the tradeoff conclusions remain the same. The increase in cryogen usage rate does permit a drastic decrease in relative insulation weight for subcritical cryogenic storage. However, the corresponding effect on total storage weight is small, increasing the weight advantage of subcritical cryogenic storage from about six percent to only about eight percent at a leakage rate of 30 pounds per day. Even if this difference were considered significant, high pressure gaseous storage would still be selected because of its superior reliability and crew time characteristics.

High pressure gaseous storage of oxygen and nitrogen is, therefore, still the best gas supply method regardless of leakage rate. Use of chemicals that must be decomposed for gas generation remains uncompetitive unless integrated into a Sabatier oxygen generation subsystem.

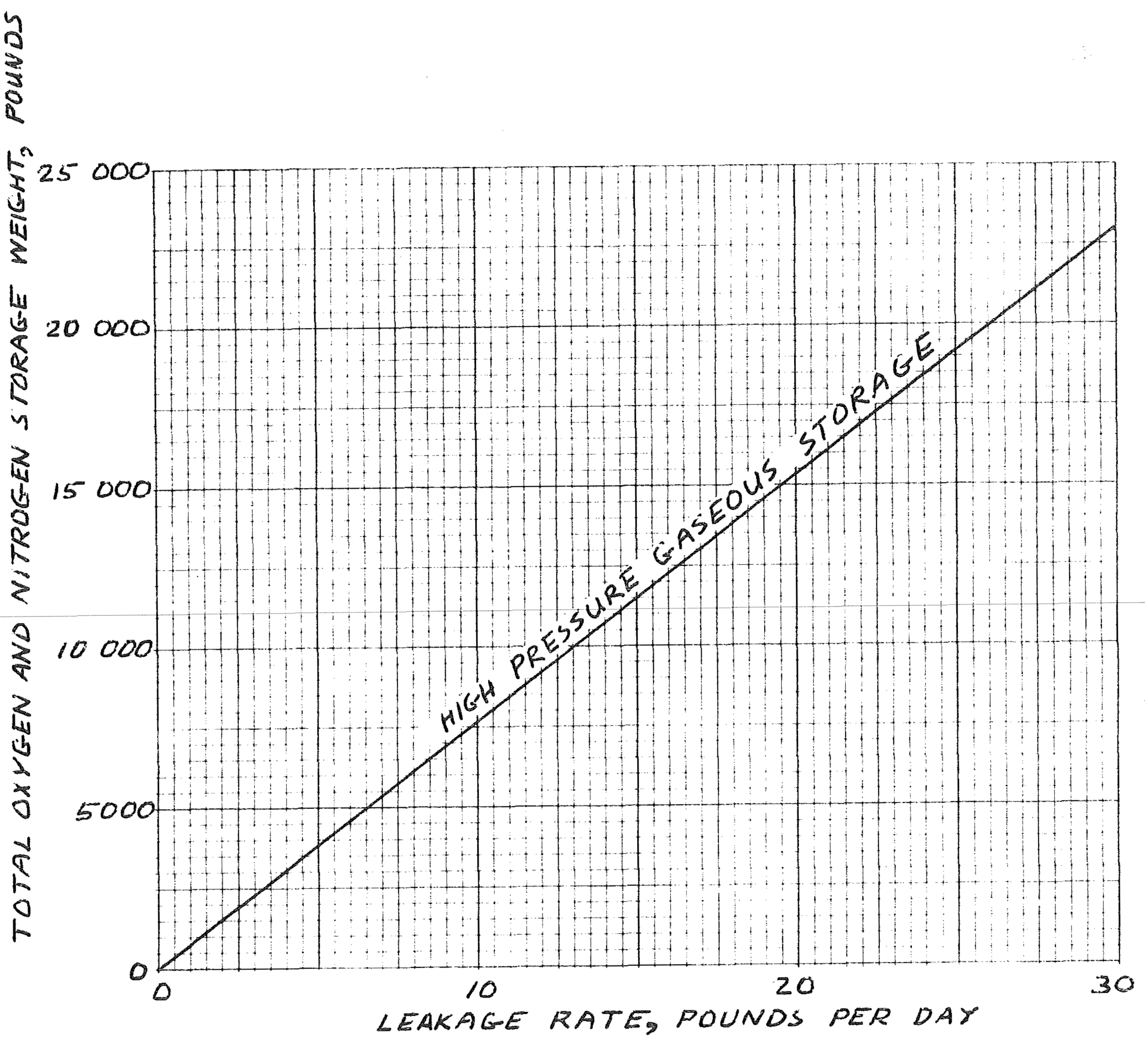

Figure 3. - Oxygen and Nitrogen Storage for Leakage Makeup

OXYGEN GENERATION

For the 7 psia AILSS, a Sabatier-methane dump concept integrated with hydrazine or ammonia decomposition and stored oxygen is a clear choice over the basic solid electrolyte concept for leakage rates above 12 pounds per day. At lower leakage rates, the solid electrolyte concept has a significant weight advantage and is, therefore, selected. This conclusion is valid for the AILSS conditions, summarized in table 1, and may not be justifiable for different total pressure, crew size, etc. The appendix of this report discusses other mission conditions.

At leakage rates below 22 pounds per day for the hydrazine version and 14 pounds per day for the ammonia version, the Sabatier-methane dump concept (with hydrazine or ammonia decomposition and stored oxygen) does the following:

a. Provides nitrogen for leakage makeup by decomposition of stored hydrazine or ammonia

b. Supplies oxygen for leakage makeup and part of the metabolic requirement from high-pressure, gaseous, stored oxygen

c. Reclaims additional metabolic oxygen by reduction of part of the collected carbon dioxide

d. Dumps unreacted carbon dioxide to space along with the byproduct methane

At higher leakage rates, all carbon dioxide is reacted, and this Sabatier concept does the following:

a. Provides nitrogen for leakage makeup by decomposition of stored hydrazine or ammonia

b. Supplies oxygen for leakage makeup from high-pressure, gaseous, stored oxygen

c. Reduces all of the collected carbon dioxide for generation of metabolic oxygen

The ammonia version of this Sabatier-methane dump-oxygen storage concept is preferred for leakage rates between 12 and 17 pounds per day because of its lower equivalent weight. The hydrazine decomposition version is

TABLE 1. - AILSS Conditions

Mission Model			
Operational period	1976-1980		
Mission duration	500 days		
Resupply capability	None		
Gravity mode	0 to 1 "G"		
Mission objective	Extended duration		
Crew Model			
Number of crewmen	9		
Metabolic activity	150% BMR		
Vehicle volume	10 000 ft^3		
Atmosphere Model			
Nominal cabin pressure	7.0 psia		
Gas composition	3.5 psia oxygen Diluent nitrogen		
CO_2 partial pressure	0.50 to 0.75 percent of total pressure		
Relative humidity	55 percent		
Temperature	65° to $75^{\circ}F$		
Power Model Designs			
	1	2	3
Electrical source	Solar cell battery	Solar cell battery	Brayton cycle (radioisotope)
Process heat source	Electrical energy	Radioisotope	Power system waste heat
Maximum heat source temperature	-	$1600^{\circ}F$	$375^{\circ}F$
Electrical power penalty	450 lb/kW	450 lb/kW	450 lb/kW

preferred for leakage rates of more than 17 pounds per day because of its lower equivalent weight and/or lower expendable storage volume. In the leakage range where these Sabatier concepts are competitive (above 12 pounds per day), their outstanding qualities are low scheduled crew time and low equivalent weight. Another Sabatier concept, which provides oxygen by electrolysis of stored water and nitrogen by hydrazine decomposition, has a very competitive equivalent weight at leakage rates above seven pounds per day, but its predicted failure rate is excessive in this range.

In the Advanced Integrated Life Support System selected for a leakage rate of one pound per day, the oxygen and nitrogen storage subsystem supplied leakage makeup from stored gases, and an independent oxygen generation subsystem (solid electrolyte) supplied the metabolic oxygen requirement. For leakage makeup, gas supplied by decomposition of stored liquids such as water or hydrazine was unattractive partly because the hydrogen byproduct was wasted. For oxygen generation, the Sabatier-methane dump concept was unattractive mainly because of the weight associated with the stored hydrogen. These two facts suggest integration of oxygen and nitrogen storage with oxygen generation, but this is not practical at the low AILSS leakage rate because the hydrogen byproduct is sufficient only to reduce a fraction of the collected carbon dioxide.

If the cabin leakage rate has the same order-of-magnitude as the metabolic oxygen consumption rate, however, the hydrogen byproduct from liquid decomposition may be used in a Sabatier reaction, and this eliminates the need for stored hydrogen. Figure 4 shows a simplified example of this concept. In this example, water is an oxygen-containing liquid, which is decomposed in an electrolysis unit to yield oxygen and hydrogen. The quantity of hydrogen generated is just sufficient to reduce all of the carbon dioxide, and the oxgyen generated is just sufficient to supply both the metabolic oxygen requirement and the oxygen leakage makeup requirement.

Decomposition of liquids other than water may be considered. Some of the more practical alternatives are included in the following list and in figure 5.

Oxygen-Containing Compounds	Nitrogen-Containing Compounds
Oxygen - O_2	Nitrogen - N_2
Water - H_2O	Hydrazine - N_2H_4
Hydrogen peroxide - H_2O_2	Ammonia - NH_3
Nitrogen tetroxide - N_2O_4	Nitrogen tetroxide - N_2O_4

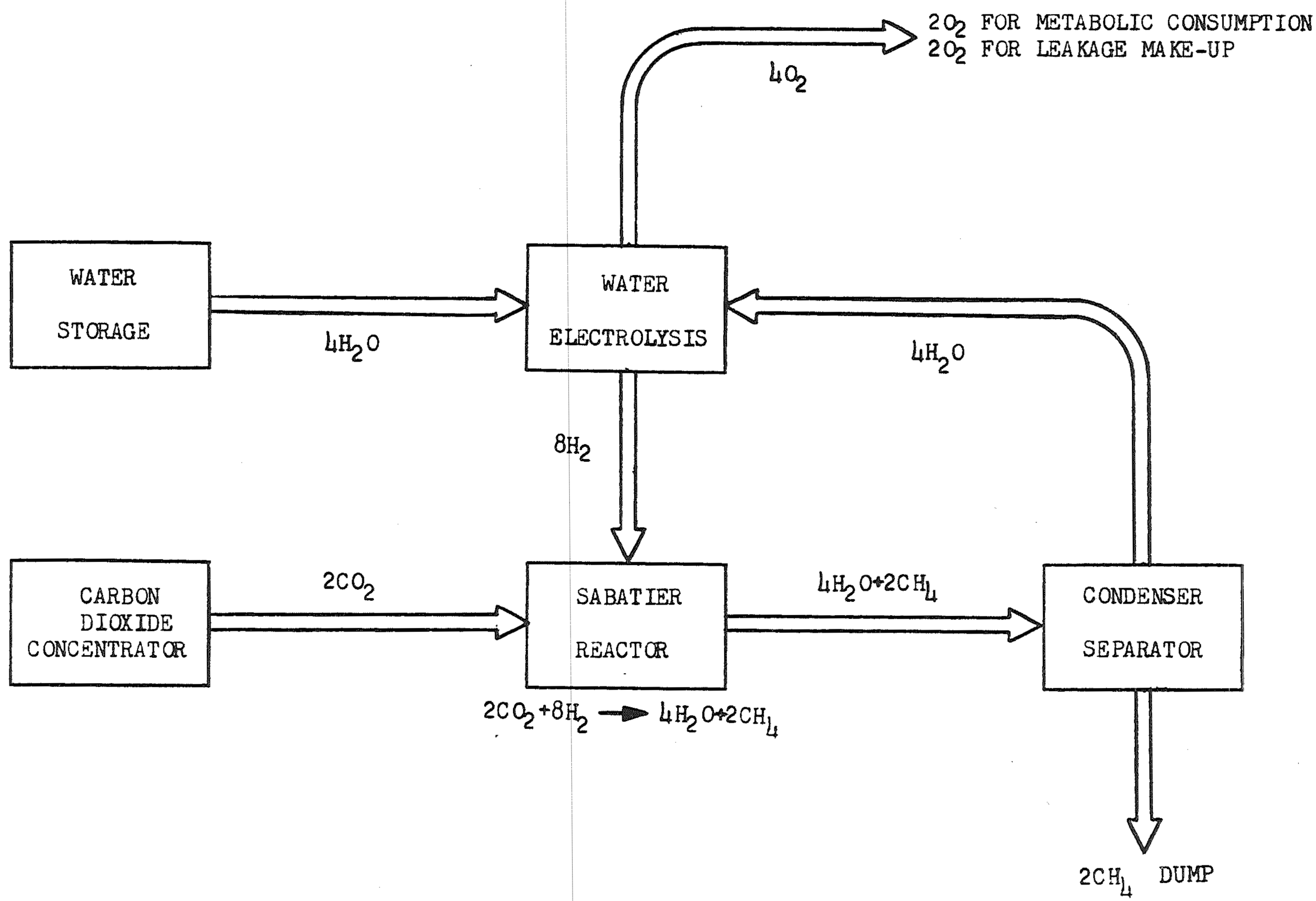

Figure 4.- Ideal Materials Balance

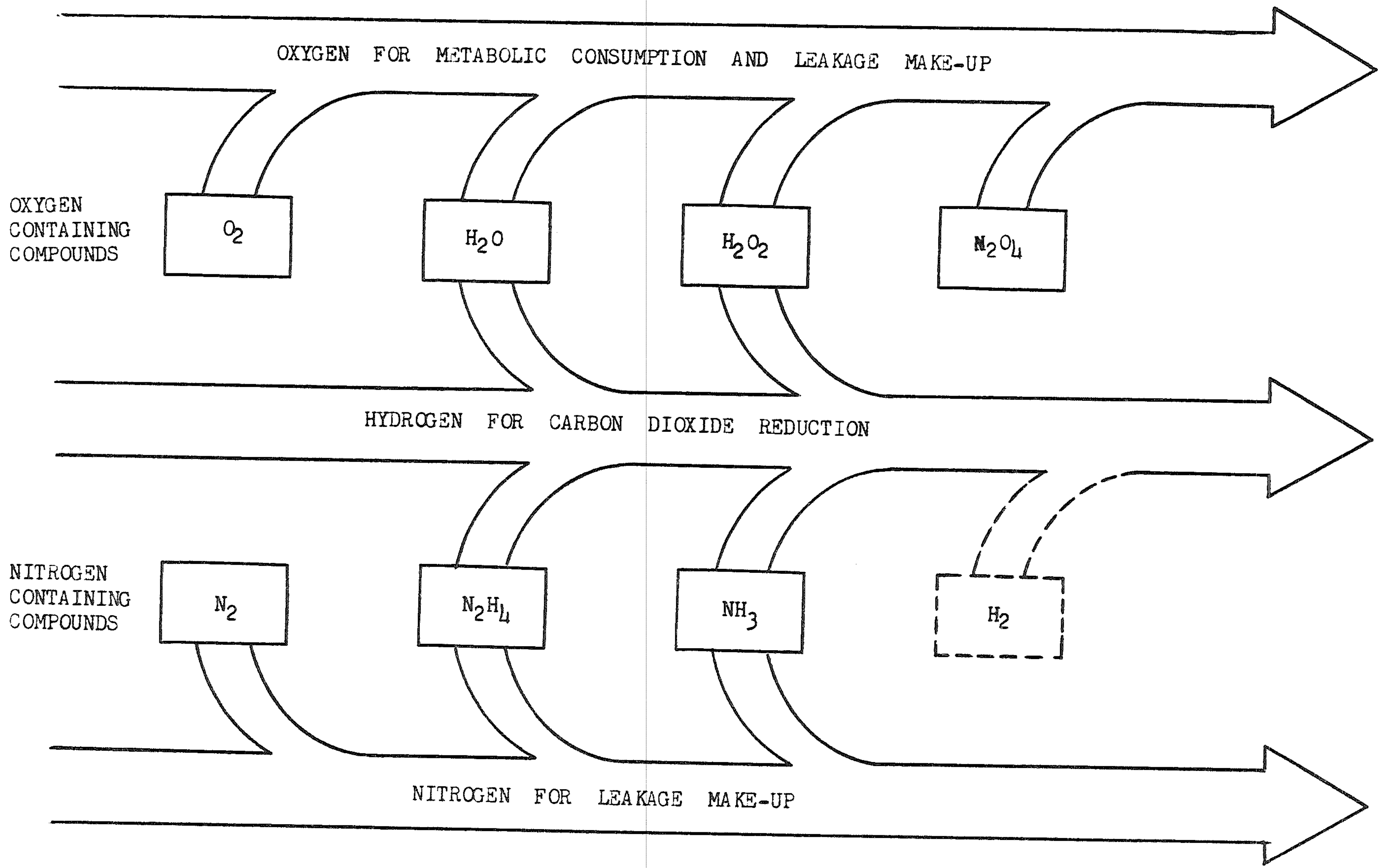

Figure 5. - Alternative O_2 and N_2 Supply Combinations

Any combination of an oxygen-containing compound and a nitrogen-containing compound used with a Sabatier-methane dump oxygen generation system will supply oxygen for metabolic consumption, oxygen for leakage makeup, and nitrogen for leakage makeup. The attractiveness of such combinations will be determined later in this section by comparing them with each other and with the selected low-leakage combination of high pressure oxygen and nitrogen and a solid electrolyte oxygen generation unit.

First, consider the general materials balance. Figure 4 represented a perfect balance between oxygen leakage and metabolic oxygen consumption. Water decomposition generated just enough hydrogen to reduce all of the carbon dioxide. At higher or lower leakage rates, this balance is upset, although the advantage of elimination of stored hydrogen is retained. At higher leakage rates, more water must be decomposed for oxygen leakage makeup, and the excess hydrogen from this additional water must be dumped to space and represents a penalty. At lower leakage rates, hydrogen generated by water decomposition is insufficient to reduce all of the carbon dioxide, and excess carbon dioxide must be dumped to space and represents a penalty. The same reasoning applies when a different hydrogen-oxygen compound is decomposed or when a hydrogen-nitrogen compound is decomposed. An additional element in the AILSS materials balance is the 1.8 pounds per day of "excess" water available for decomposition to provide hydrogen and part of the oxygen requirement. This water excess appears in the overall water management materials balance and its source may be regarded as metabolic oxidation of hydrogen in the food.

Although the Bosch concept for carbon dioxide reduction uses hydrogen, it is essentially a closed loop process and does not require an external source of hydrogen. Thus, its evaluation relative to the solid electrolyte concept is not influenced by leakage rate, and the Bosch concept need not be considered in this study.

The remainder of this section describes the variations on the Sabatier-methane dump concept and compares them with the solid electrolyte concept. The basis for the oxygen generation concept selection conclusion stated at the beginning of the section is presented. For a meaningful comparison, the systems discussed here provide both oxygen and nitrogen leakage makeup, as well as metabolic oxygen. For consistency with the AILSS Final Report, these systems include carbon dioxide concentration. In the discussion, the concepts are grouped for convenience.

Concept Descriptions

The basic solid electrolyte and Sabatier-methane dump concepts were described thoroughly in the AILSS Final Report. The only difference in these basic concepts at other leakage rates is that the oxygen and nitrogen tanks vary in size, according to the leakage rate. The additional Sabatier-methane dump concepts to be considered here (including the basic oxygen-nitrogen-hydrogen concept considered in the AILSS Final Report) are listed below. The oxygen and nitrogen are stored as high pressure gases.

Oxygen storage concepts

- Oxygen + hydrazine
- Oxygen + ammonia
- Oxygen + nitrogen-hydrogen

Water decomposition concepts

- Water + nitrogen
- Water + hydrazine
- Water + ammonia

Hydrogen peroxide concepts

- Hydrogen peroxide + nitrogen
- Hydrogen peroxide + hydrazine
- Hydrogen peroxide + ammonia

Nitrogen tetroxide concepts

- Nitrogen tetroxide + hydrazine
- Nitrogen tetroxide - decomposition

Oxygen storage concepts. - Oxygen storage versions of the Sabatier-methane dump concept all store oxygen in pure form, as a high pressure gas. The oxygen-nitrogen-hydrogen combination is the basic Sabatier concept considered in the AILSS Final Report.

The oxygen-hydrazine combination provides nitrogen for leakage makeup by decomposition of liquid hydrazine (N_2H_4). As shown in figure 6, liquid hydrazine is vaporized and decomposed as it passes through a catalytic reactor. Pure hydrogen is separated from the product mixture by a silver-palladium separator, and it is fed to the Sabatier reactor for carbon dioxide reduction. The remaining mixture contains nitrogen, unseparated hydrogen, and traces of ammonia. It is added to the feed of the cabin catalytic oxidizer, where the hydrogen is oxidized to water, the ammonia is decomposed to nitrogen and hydrogen, and the nitrogen remains unreacted. The catalytic oxidizer effluent enters the cabin atmosphere. Reliability of the equipment shown is considered very good (although lower than that of stored, gaseous nitrogen) with a mean time

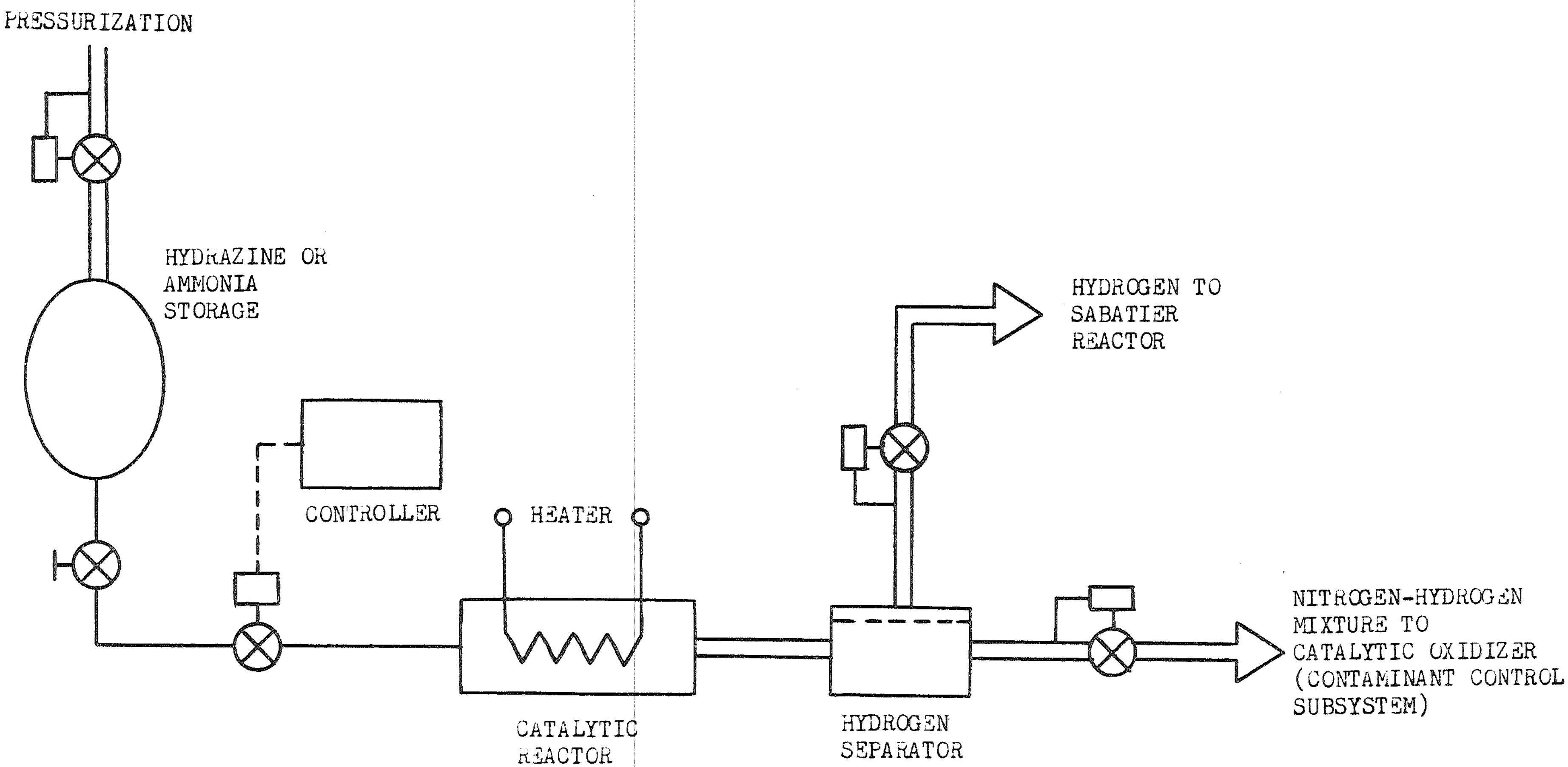

Figure 6.- Hydrazine Decomposition Unit

between failures estimated to be 61 700 hours. Safety is only fair, with hydrazine and ammonia both presenting a potential explosive and toxic hazard. The process is undeveloped for life support, but development of similar hydrazine decomposition processes for monopropellant engines and gas generators is advanced. The version described here is considered typical, although an electrochemical hydrazine decomposition process is under development.

The third combination, oxygen-ammonia, is very similar to the oxygen-hydrazine combination just described. The main differences are that ammonia contains more hydrogen per pound and that the ammonia decomposition reaction is endothermic, requiring considerable thermal power.

Water decomposition concepts. - Water decomposition concepts all store oxygen in the form of water, which is electolyzed to release the oxygen and provide byproduct hydrogen for the Sabatier reaction. The water-nitrogen combination was described earlier in this report. Its equipment is similar to that of the basic Sabatier concept (although size varies with leakage rate), but some carbon dioxide is dumped with the methane at leakage rates below 23 pounds per day. This concept has the unfortunate characteristic that failure rate increases significantly as leakage rate increases, because of the additional electrolysis modules required. The water-hydrazine combination is similar to the oxygen-hydrazine combination, described previously, except for the differences just noted. The water and hydrazine do not interact. The water-ammonia combination is similar to the water-hydrazine combination except, as before, the ammonia contains more hydrogen and requires thermal power for its decomposition.

Hydrogen peroxide concepts. - Hydrogen peroxide concepts all store oxygen in the form of hydrogen peroxide (H_2O_2), which may be regarded as oxygenated water. When it passes through a catalytic reactor, it breaks down to form water and oxygen. The hydrogen peroxide-nitrogen combination is described in the oxygen and nitrogen storage section of the AILSS Final Report. The only difference here is that hydrogen resulting from electrolysis of the product water is used for carbon dioxide reduction in a Sabatier reactor. With regard to carbon dioxide reduction, characteristics of this combination are similar to those of water-nitrogen. The hydrogen peroxide-hydrazine combination is different. Here the hydrogen peroxide (oxygen-containing) and the hydrazine (nitrogen-containing) are reacted together over a catalyst. The process is very similar to the nitrogen tetroxide-hydrazine concept discussed under the next heading. The characteristics of the hydrogen peroxide-ammonia combination are also similar.

Nitrogen tetroxide concepts. - The nitrogen tetroxide-hydrazine combination is discussed in detail in the oxygen and nitrogen storage section of the AILSS Final Report. The two liquids react to form nitrogen, oxygen, and water, which is electrolyzed to provide additional oxygen and hydrogen for carbon dioxide reduction. Simple decomposition of nitrogen tetroxide alone is an alternative that is not considered further. This decomposition reaction yields twice as much oxygen as nitrogen, whereas makeup for cabin leakage at the AILSS nominal operating pressure of 7 psia requires approximately equal quantities of the two gases. Thus, the oxygen-nitrogen ratio for this process is unsuitable for the AILSS, no hydrogen is generated, and the concept has not previously been considered for life support. Nitrous oxide (N_2O) decomposition has been considered briefly for life support, but no development work has been done, and disadvantages are similar to those of nitrogen tetroxide decomposition.

Concept Comparison

Comparison of the Sabatier variations just described among themselves, and then with the solid electrolyte concept, results in selection of oxygen generation concepts as a function of various leakage rates. The initial comparisons comprise a screening of the candidates on an equivalent weight basis. The final comparison considers all of the AILSS selection criteria.

Candidate concepts are grouped for convenience, as described earlier, and the total equivalent weights for each group are presented graphically in the next five figures. These graphs show variation of equivalent weight difference from a baseline member of the group as a function of leakage rate. Absolute weights are indicated by boundaries representing 10 percent variation from the equivalent weight of the baseline concept. In general, but not in each instance, the equivalent weight lines have two discontinuities. The first represents a leakage rate at which all collected carbon dioxide can be reacted; below this point carbon dioxide must be dumped to space, and beyond this point excess hydrogen must be dumped to space. The second discontinuity is similar to the first, but this time it is the baseline concept that actually changes, and the change is reflected in the equivalent weight lines of the other candidates. For consistency, the baseline concepts are those that most closely resemble the AILSS.

For reasons discussed earlier, all of the equivalent weights reflect the following elements:

Storage of oxygen or oxygen-containing liquid
Storage of nitrogen or nitrogen-containing liquid

Storage of hydrogen where not included in the above
Carbon dioxide concentration
Carbon dioxide reduction
Water electrolysis for Sabatier concepts
Decomposition of oxygen or nitrogen-containing liquids

Weights of expendables were determined by a materials balance, which is discussed further in the appendix.

Oxygen storage concepts. - Figure 7 shows the equivalent weight relationships within the oxygen storage candidates group. The oxygen-nitrogen-hydrogen (O_2-N_2-H_2) baseline combination is essentially the basic Sabatier-methane dump concept described in the AILSS Final Report. At low leakage rates, the candidates providing nitrogen by liquid decomposition (O_2-N_2H_4 and O_2-NH_3) have high equivalent weight, because the hydrogen contained in these liquids is insufficient to reduce all of the carbon dioxide, and gaseous oxygen must be stored to make up for the oxygen contained in the dumped carbon dioxide. Up to a leakage rate of about 17 pounds per day, ammonia decomposition shows a small (relatively) advantage over hydrazine decomposition. This advantage results from the greater amount of hydrogen available for carbon dioxide reduction. This situation is, however, reversed beyond 17 pounds per day leakage, when the excess hydrogen must be dumped and is, therefore, a weight penalty. Hydrazine decomposition is the best overall candidate at substantial leakage rates.

Water decomposition concepts. - At low leakage rates, none of the water decomposition concepts shown in figure 8 provides hydrogen sufficient to prevent dumping carbon dioxide. As leakage rate increases, however, the hydrazine and ammonia decomposition versions (H_2O-N_2H_4 and H_2O-NH_3) provide hydrogen from both water and the nitrogen-containing liquid. These two versions maintain the same general relationship they did in the oxygen storage candidates, and hydrazine decomposition is again the best overall choice.

Hydrogen peroxide concepts. - Figure 9 shows the equivalent weight relationships for the hydrogen peroxide group of candidates. The situation is qualitatively the same as that for water decomposition, except that the nitrogen storage version (H_2O_2-N_2) has the lowest weight for leakage rates above 35 pounds per day. Nevertheless, hydrazine for nitrogen makeup again represents the best overall choice within the range considered.

Hydrazine decomposition candidates. - The previous comparisons all indicated that versions providing nitrogen from hydrazine were the most competitive overall, although ammonia versions had somewhat lower

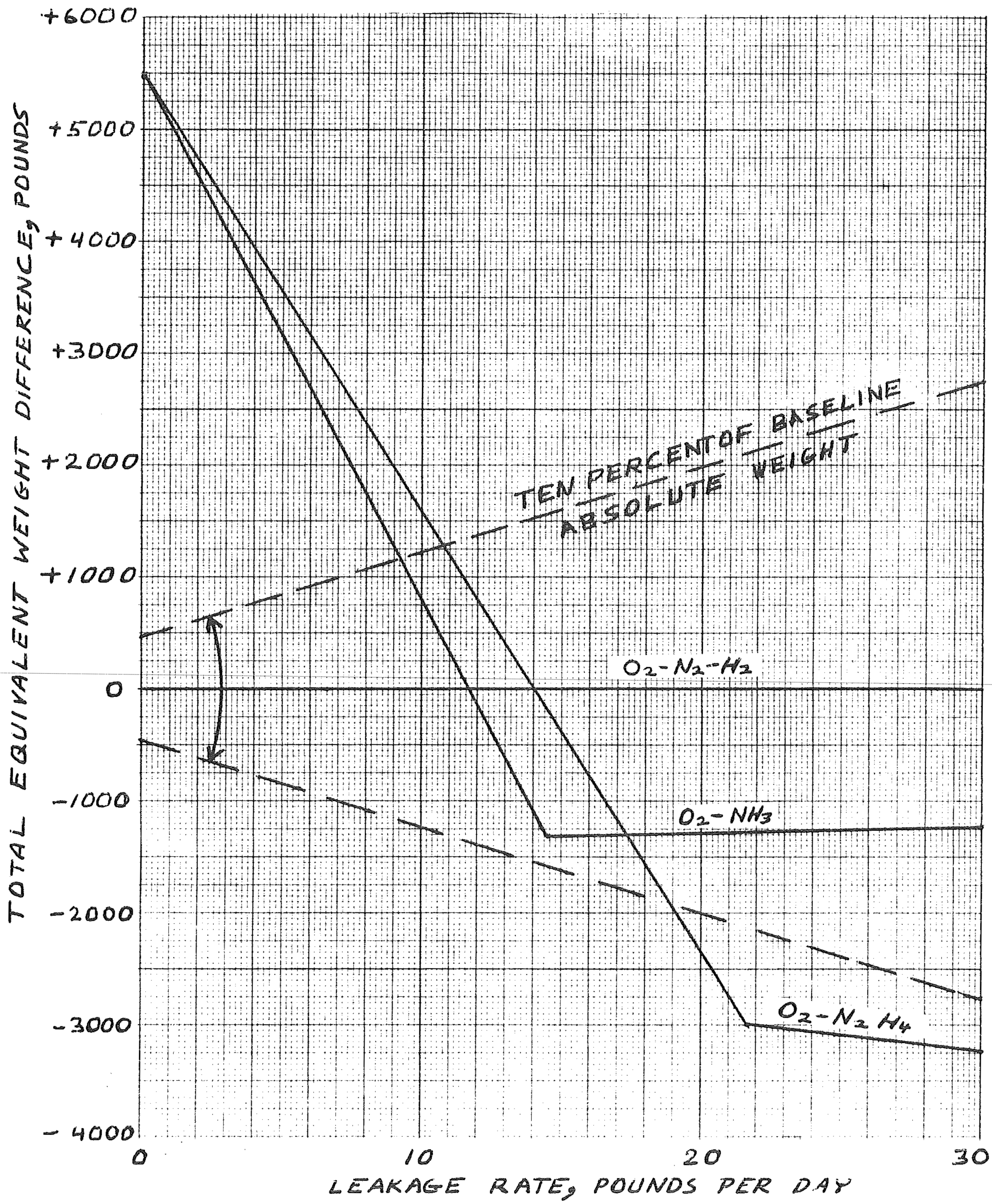

Figure 7. - Oxygen Storage Concepts

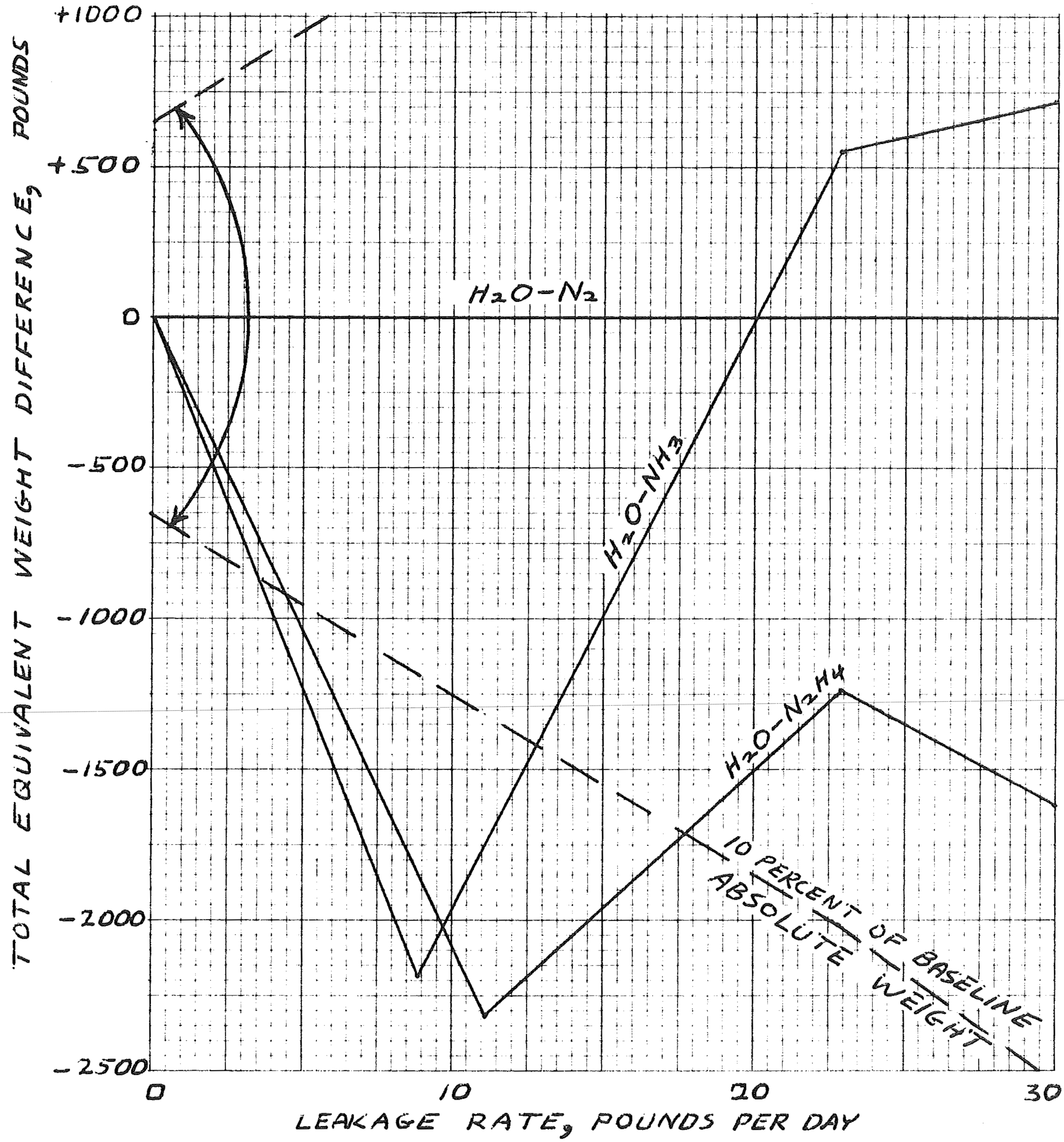

Figure 8. - Water Decomposition Concepts

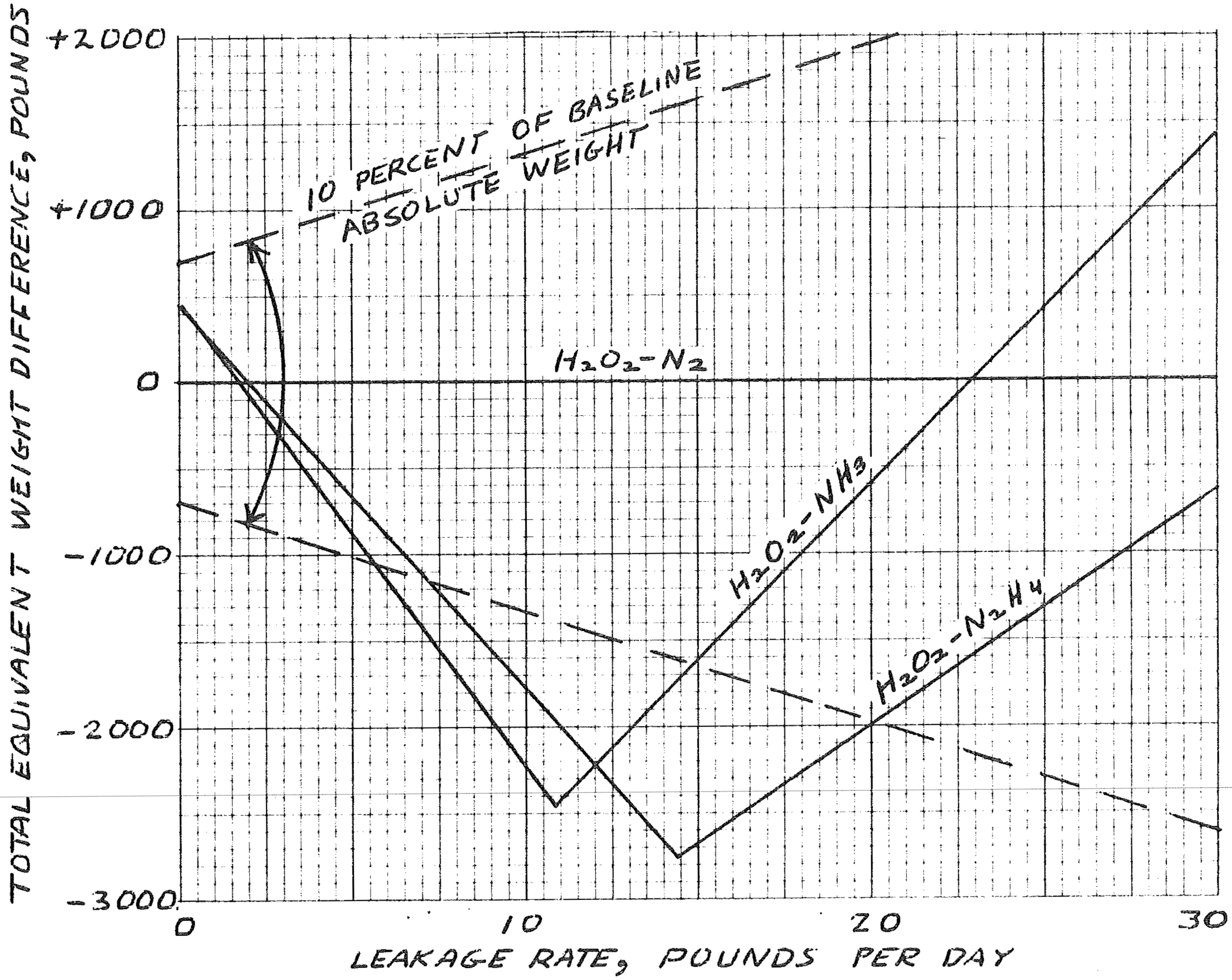

Figure 9. - Hydrogen Peroxide Concepts

equivalent weights for some leakage rates. Consequently, figure 10 shows all concepts involving hydrazine, including the hydrazine-nitrogen tetroxide combination (N_2O_4-N_2H_4) not previously shown. This combination is unique in that nitrogen is provided by both liquids, and the resulting materials balance is more flexible and complex than for other combinations. Figure 9 assumes that hydrazine sufficient to reduce all carbon dioxide is used, and that nitrogen tetroxide is used to provide sufficient makeup for leaked oxygen. No combination of the two chemicals appears competitive, however. Two important conclusions, to be considered in the final comparison, are evident. First, the water-hydrazine combination (H_2O-N_2H_4) is competitive at higher leakage rates. Second, the oxygen-hydrazine combination (O_2-N_2H_4) is competitive at higher leakage rates.

Concept selection. - Figure 11 shows an equivalent weight comparison between the solid electrolyte baseline and the most competitive Sabatier concepts. The Sabatier concepts are not competitive at very low leakage rates because excessive oxygen, in the form of oxygen or water, is needed to make up for the oxygen lost in the dumped carbon dioxide. At increased leakage rates, the Sabatier concepts become increasingly competitive, until equivalent weight differences are no longer significant. To select a concept in this leakage range, all of the AILSS selection criteria must be considered.

The AILSS Final Report showed that the Sabatier-methane dump concept had superior absolute characteristics. In particular, its availability was exceptional. If hydrazine or ammonia decomposition is added to this concept, however, its availability is not nearly as good, because the process has not been developed for life support application. Consequently, absolute characteristics of Sabatier with hydrazine or ammonia decomposition are considered roughly equivalent to those of solid electrolyte.

The primary criteria are reliability, crew time, and equivalent weight. The solid electrolyte and Sabatier-methane dump concepts had equal reliability ratings, and although Sabatier had a definite advantage in crew time, its equivalent weight was excessive. The Sabatier versions considered here (with hydrazine or ammonia decomposition) require somewhat more unscheduled crew time, but they retain the basic advantage because handling of carbon-filled catalyst cartridges is not necessary. Inherent reliability and equivalent weight are, therefore, the key elements of this comparison.

Equivalent weight was shown in figure 11. Figure 12 shows the influence of leakage rate on MTBF (mean time between failures), a measure of inherent reliability. One message implicit in these curves

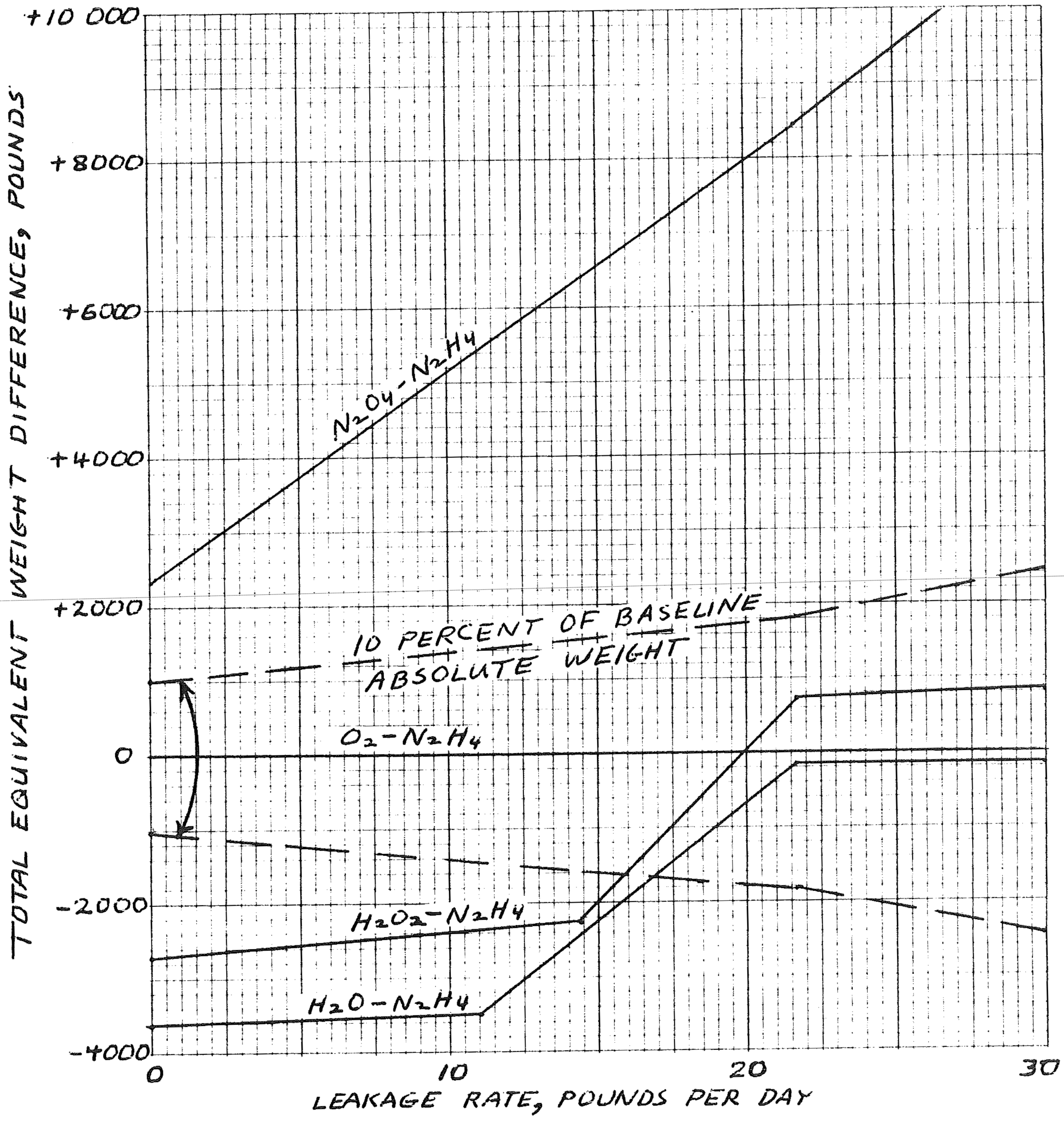

Figure 10. - Hydrazine Concepts

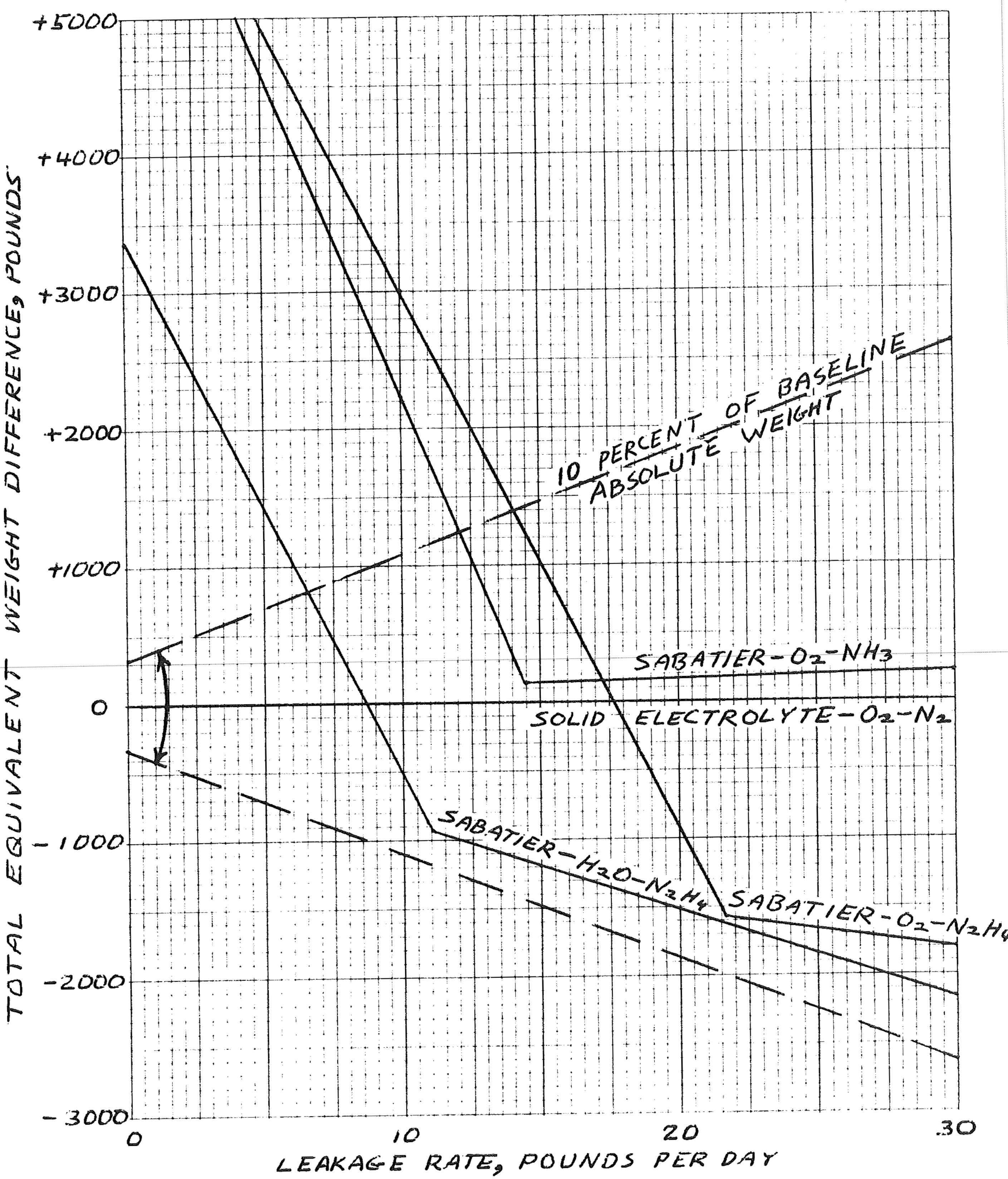

Figure 11. - Leading Candidate Concepts

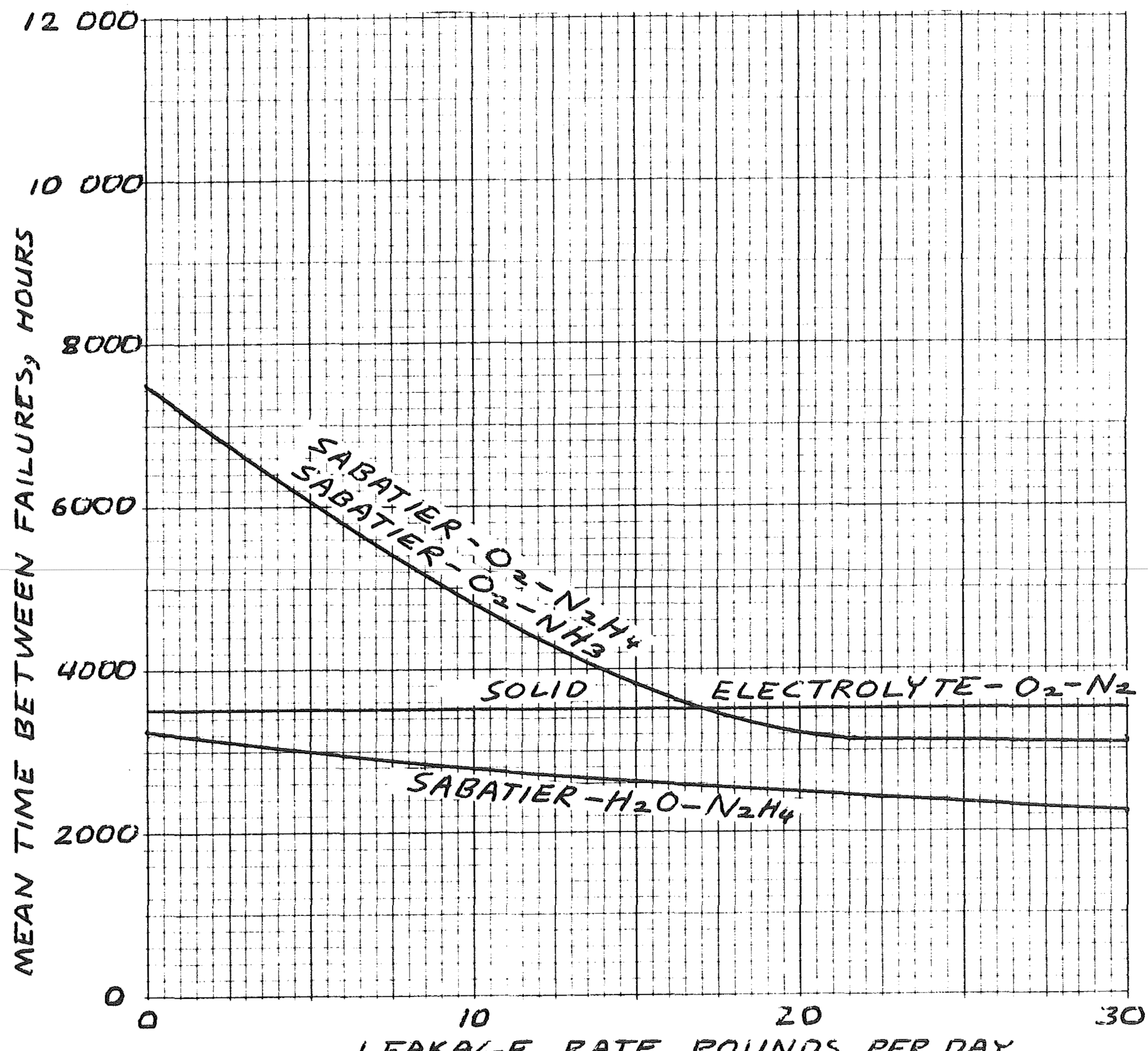

Figure 12. - Concept Inherent Reliability

is that oxygen from a stored gas supply is much more reliable than oxygen from electrolysis of stored water. At higher leakage rates, the Sabatier-oxygen-hydrazine or ammonia curve is intermediate between the other two, because the only incremental water electrolysis is that required by the inefficiency of the hydrogen separator (unseparated hydrogen is oxidized to water).

Considering both equivalent weight and inherent reliability (figures 11 and 12), equivalent weight of the Sabatier-water-hydrazine concept becomes fully competitive at a leakage rate of seven pounds per day, but its failure rate becomes excessive (the MTBF of 3000 represents four failures during the average mission) at five pounds per day. At a slightly lower leakage rate, about three pounds per day, this concept has higher equivalent weight than solid electrolyte, but lower crew time. It is in this narrow leakage range (about three to five pounds per day) that the Sabatier-hydrazine-water concept is most competitive, but both its absolute criteria and its secondary criteria (especially interface complexity and flexibility) are considered slightly inferior to those of solid electrolyte. In summary, the Sabatier-water-hydrazine concept is not considered further, because at any leakage rate either its equivalent weight is too high or its reliability is too low.

This leaves the Sabatier-oxygen-hydrazine and ammonia concepts to be examined in a similar manner. Their equivalent weights become fully competitive at leakage rates of 12 pounds per day for the ammonia version and 14 pounds per day for the hydrazine version. Reliability is acceptable up to a leakage rate of about 70 pounds per day. Hence, for reasonable leakage rates, the Sabatier-methane dump concept, with stored oxygen and hydrazine or ammonia decomposition, is selected for an AILSS with more than 12 pounds per day leakage, because of its superior crew time characteristics. Solid electrolyte, with oxygen and nitrogen storage, remains the best choice for lower leakage rates, where it has far lower equivalent weight. Absolute equivalent weights of the selected system concepts are shown in figure 13, and table 2 shows an evaluation summary based on the AILSS trade-off criteria, for both the original low-leakage AILSS and a high-leakage-rate (12 to 70 pounds per day) AILSS.

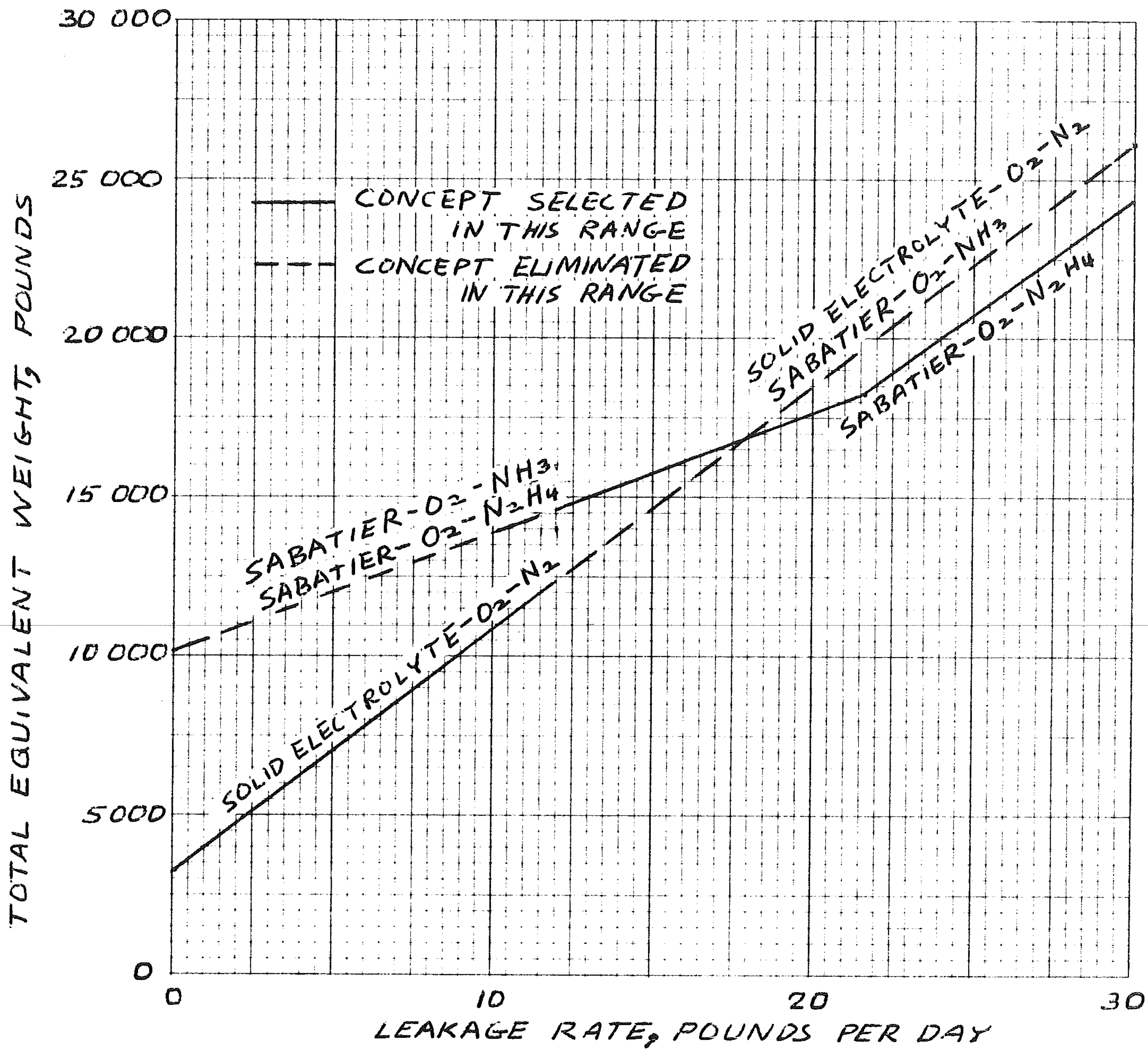

Figure 13. - Selected Oxygen Generation Concepts

TABLE 2: OXYGEN GENERATION EVALUATION SUMMARY

Power Supplies Design 1 - Solar Cell Design 2 - Solar Cell/ Isotopes Design 3 - Brayton		Leakage = 1 lb/day		Leakage = 14 lb/day	
		Solid Electrolyte - Gaseous O_2 and N_2	Sabatier-methane dump - Gaseous O_2 - N_2H_4 Decomp.	Solid Electrolyte - Gaseous O_2 and N_2	Sabatier-methane dump - Gaseous O_2 N_2H_4 Decomp.
CRITERIA / DESIGN		1 2 3	1 2 3	1 2 3	1 2 3
Absolute	Performance	Good	Good	Good	Good
	Safety	Fair	Fair	Fair	Fair
	Avail./Conf.	Fair	Fair	Fair	Fair
Primary	Reliability	Fair	Fair	Fair	Fair
	Crew Time	Good	Very Good	Good	Very Good
	Equivalent Weight	Very Good	Poor	Very Good	Very Good
			Eliminated	Eliminated	
Secondary	Contamination	Fair			Fair
	Interfaces	Good			Poor
	Flexibility	Good			Fair
	Growth	Good			Good
	Noise	Good			Very Good
	Volume	Good			Very Good
	Power	Good			Good
		Selected			Selected

ATMOSPHERIC CONTAMINATION CONTROL

The AILSS atmospheric contamination control subsystem is designed for zero leakage, regardless of actual leakage. Vehicle leakage would carry a portion of the contaminants overboard. This would keep the contaminants at lower concentrations than anticipated, resulting in an added safety margin. Even if the overall system were designed for a specific leakage rate, actual leakage would undoubtedly be lower, necessitating a zero leakage contaminant control design.

Forcing the actual leakage rate to equal the design rate (by continuous addition of stored oxygen and nitrogen to the cabin atmosphere) is unreasonable, because the unused expendables would provide insurance against a sudden, high-rate leak. Nevertheless, if a specific leakage rate were assured, the contaminant control subsystem equivalent weight could be reduced. This reduction would result from the fact that process flow rates through the sorbent bed and catalytic oxidizer could be decreased by an amount equal to the leakage rate. That is, a contaminant is removed just as surely by leakage as by sorption or catalytic oxidation. Thus, a leakage rate of 160 pounds per day would eliminate the need for a catalytic oxidizer, while a much higher rate would be necessary to eliminate the need for ammonia control. The influence of assured leakage on trace gas control subsystems equivalent weight is shown in figure 14. In conclusion, use of the AILSS trace contaminant control subsystem, as described in the final report, is recommended for any reasonable leakage rate.

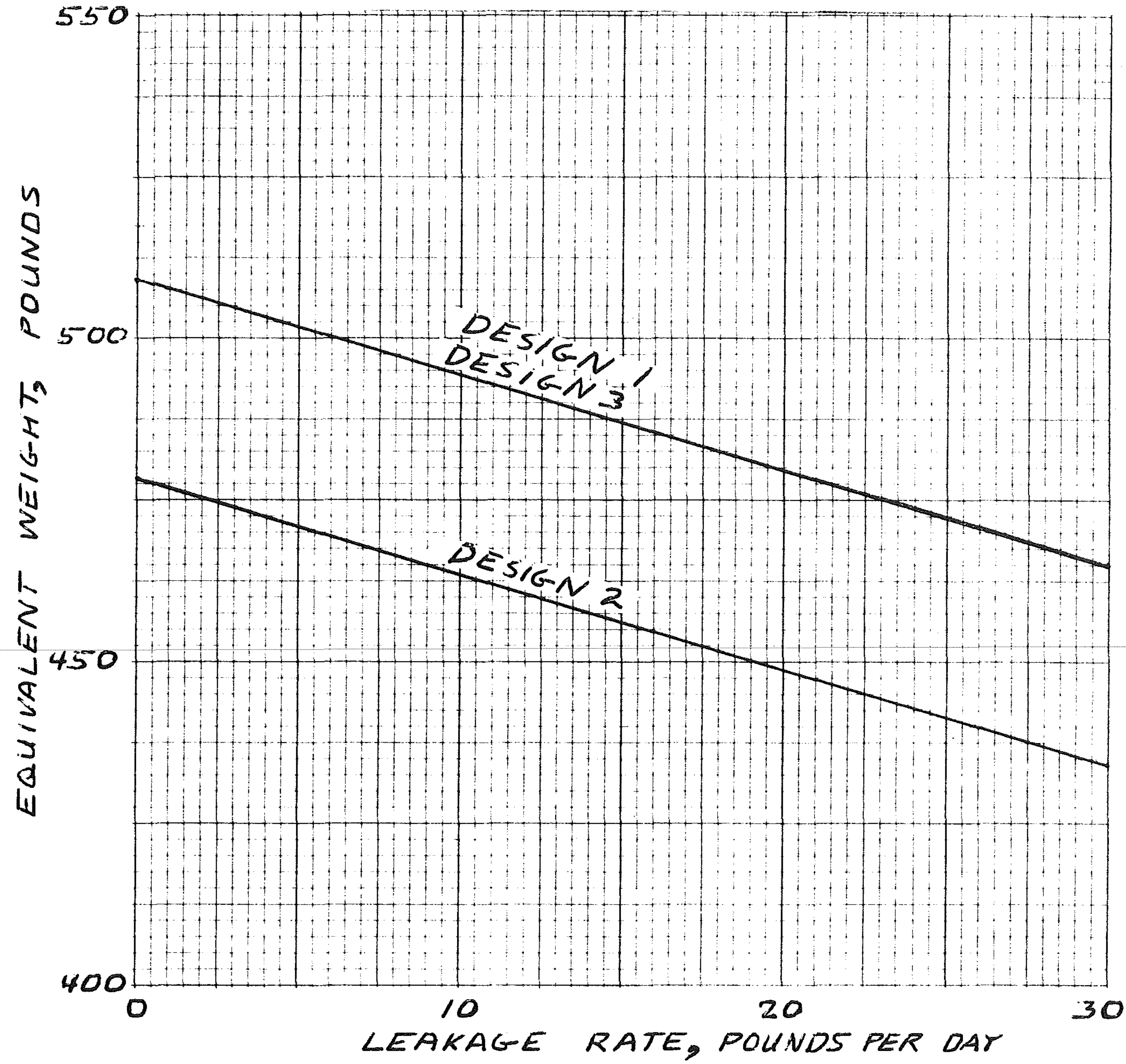

Figure 14. - Trace Contaminant Control

WATER MANAGEMENT

Vapor diffusion/compression (solar cell design) and vapor diffusion (solar cell-isotope and Brayton cycle designs) remain the best selections for water recovery, regardless of leakage rate. Although a credit for recovery of extra water can result in selection of the closed cycle air evaporation concept for the water management subsystem at some leakage rates, system considerations show that such a credit may not be relevant from the system-level viewpoint.

The selected vapor diffusion concepts recover potable water from the contaminated water to a point where residual unrecovered water represents a loss of 1.53 pounds of water per day. This water is not needed to achieve satisfactory AILSS water balance. However, if leakage rate were more than one pound per day, electrolysis of this residual water to provide makeup oxygen would be valuable. The air evaporation concept can recover nearly all of this residual water (that is, air evaporation leaves practically no residual water) and, on a subsystem basis, was given a credit for it based on contained oxygen. Figure 14 reflects this apparent credit, which reaches a maximum of about 1000 pounds at a leakage rate of about three pounds per day. For better perspective, the equivalent weights shown in figure 14 include the weight of stored oxygen for leakage makeup; that is, oxygen for leakage makeup is shown as a debit to vapor diffusion rather than a credit to air evaporation. Figure 15 is consistent with the AILSS assumption of 95 percent water recovery capability for the vapor diffusion concepts, although recent development tests show that 98 percent efficiency is attainable. Despite the superior absolute characteristics (particularly safety) of the vapor diffusion concepts, the closed air evaporation concept is highly competitive at leakage rates above 2.5 pounds per day.

Nevertheless, the residual water in question can also be recovered in the waste control subsystem, and there are several reasons for preferring that approach. First it permits the use of vapor diffusion with its inherent bacteria control characteristics. Second, required modification of the waste control subsystem is relatively minor. Third, if recovery of residual water is necessary, then recovery of water from food wastes is probably desirable, and this must be done in the waste control subsystem anyway. This topic is discussed further in the next section.

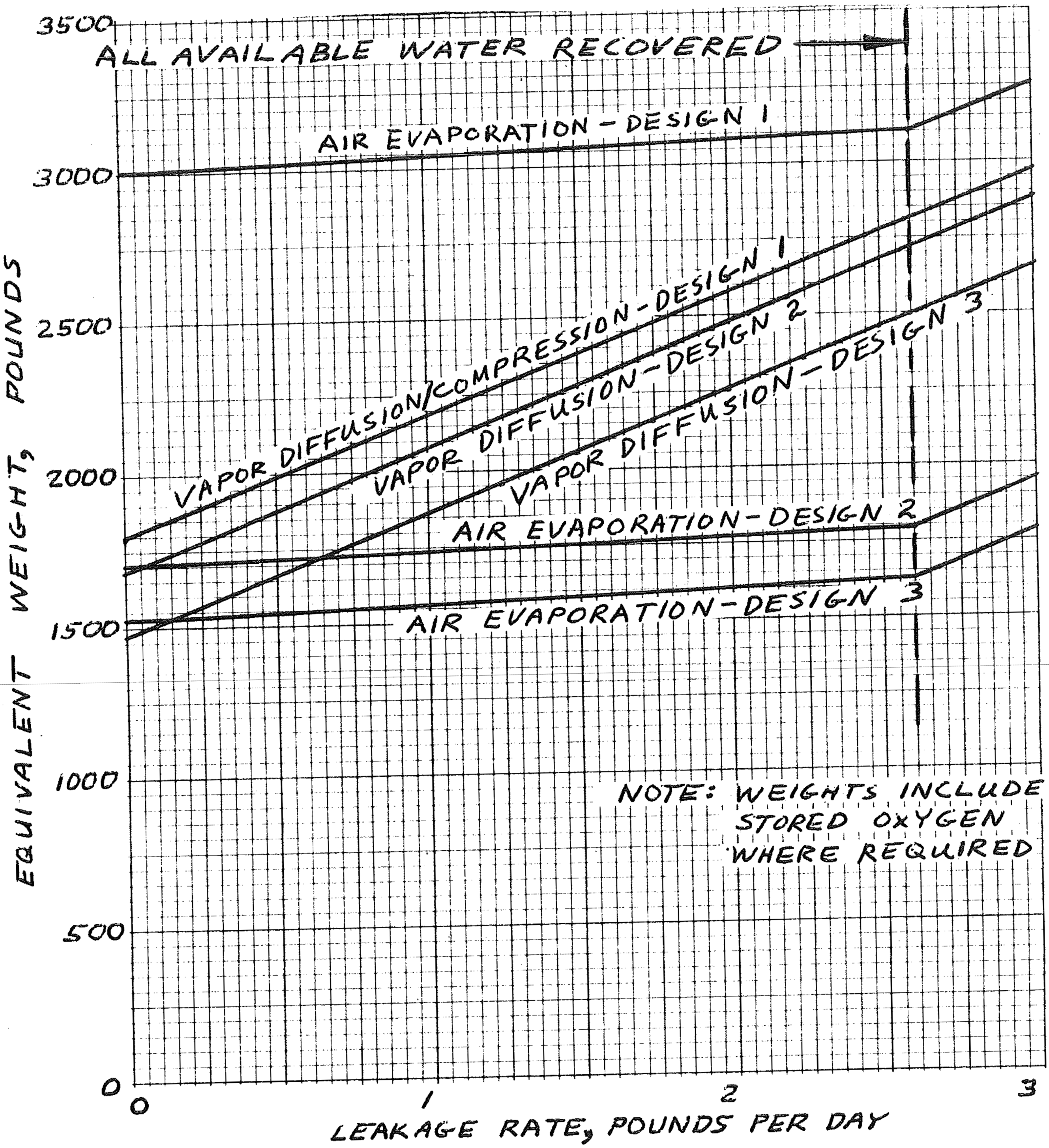

Figure 15. - Water Reclamation

WASTE CONTROL

Waste materials contain water from three sources, listed below:

Water management residuum	1.53 lb/day
Food wastes	1.29
Feces	2.25

The fecal water, however, is considered unrecoverable, because it may contain clostridium botulinum spores which could release lethal toxin if recovery of this water were attempted (nevertheless, use of recovered fecal water for electrolysis might be safe). For a leakage rate of five pounds per day or more, recovery of all water in food and water management wastes would obviate the need to store 1300 pounds of oxygen for leakage makeup.

The penalty for achieving this saving is approximately 300 pounds, which is less than the weight of the eliminated oxygen tank. Therefore, the net saving for recovery of this waste water is over 1300 pounds, which is well worthwhile. Figure 16 shows the weight saving for various leakage rates. Equipment added to the AILSS selected vacuum decomposition concept to achieve the indicated savings would consist of a condenser-separator, a water line, and associated valves, as shown in figure 17. The condenser-separator could be eliminated by directing the vacuum pump effluent to the cabin humidity control equipment. A change of crew routine would also be necessary. Food wastes and water management residuum would be emptied into a sterile waste collector that had completed the vacuum decomposition portion of the cycle. These wastes would then be heated moderately, and the resulting water vapor would be removed by the vacuum pump. The waste collector would then be used for normal fecal collection and processing, as described in the AILSS Final Report.

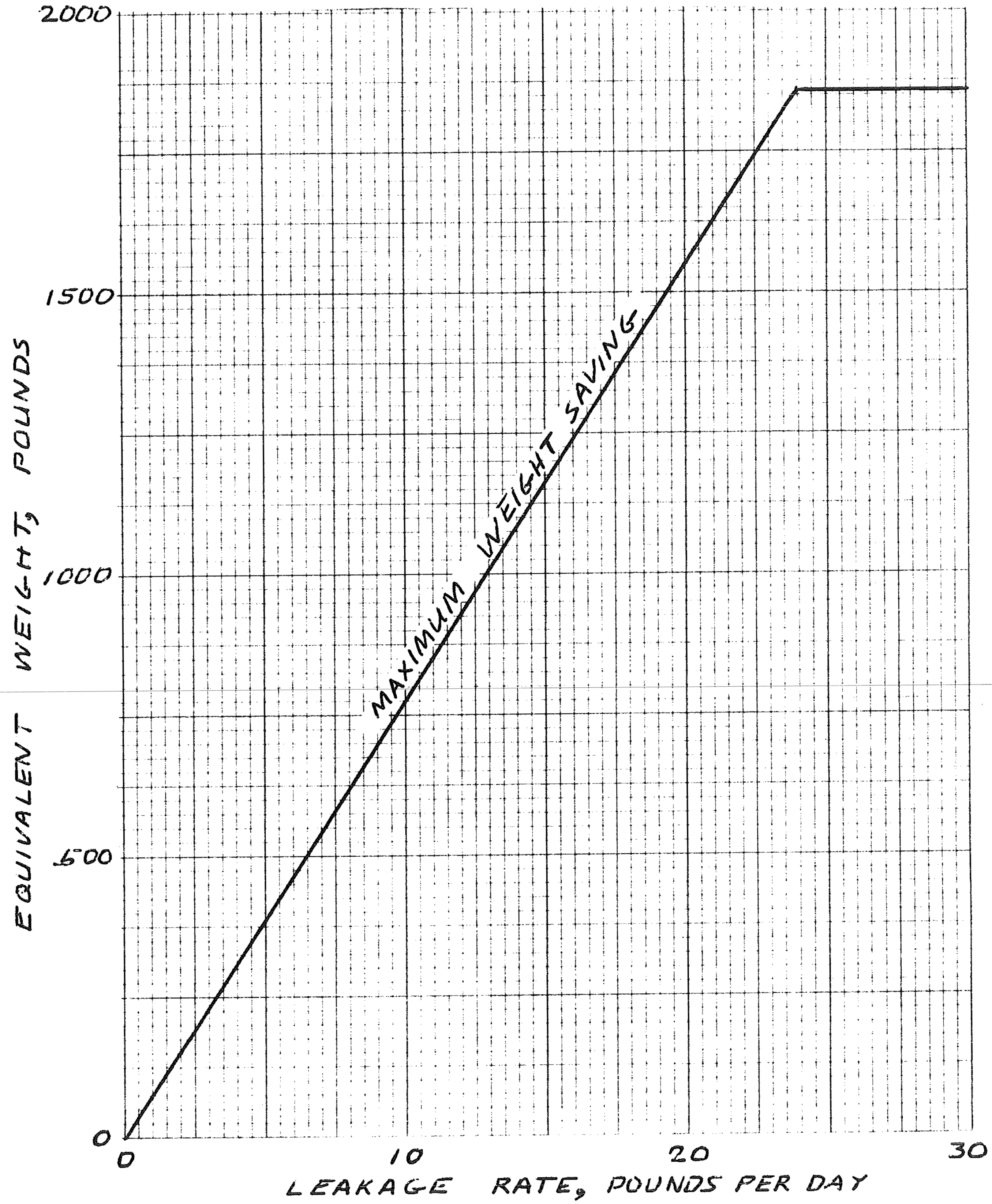

Figure 16. - Waste Water Recovery

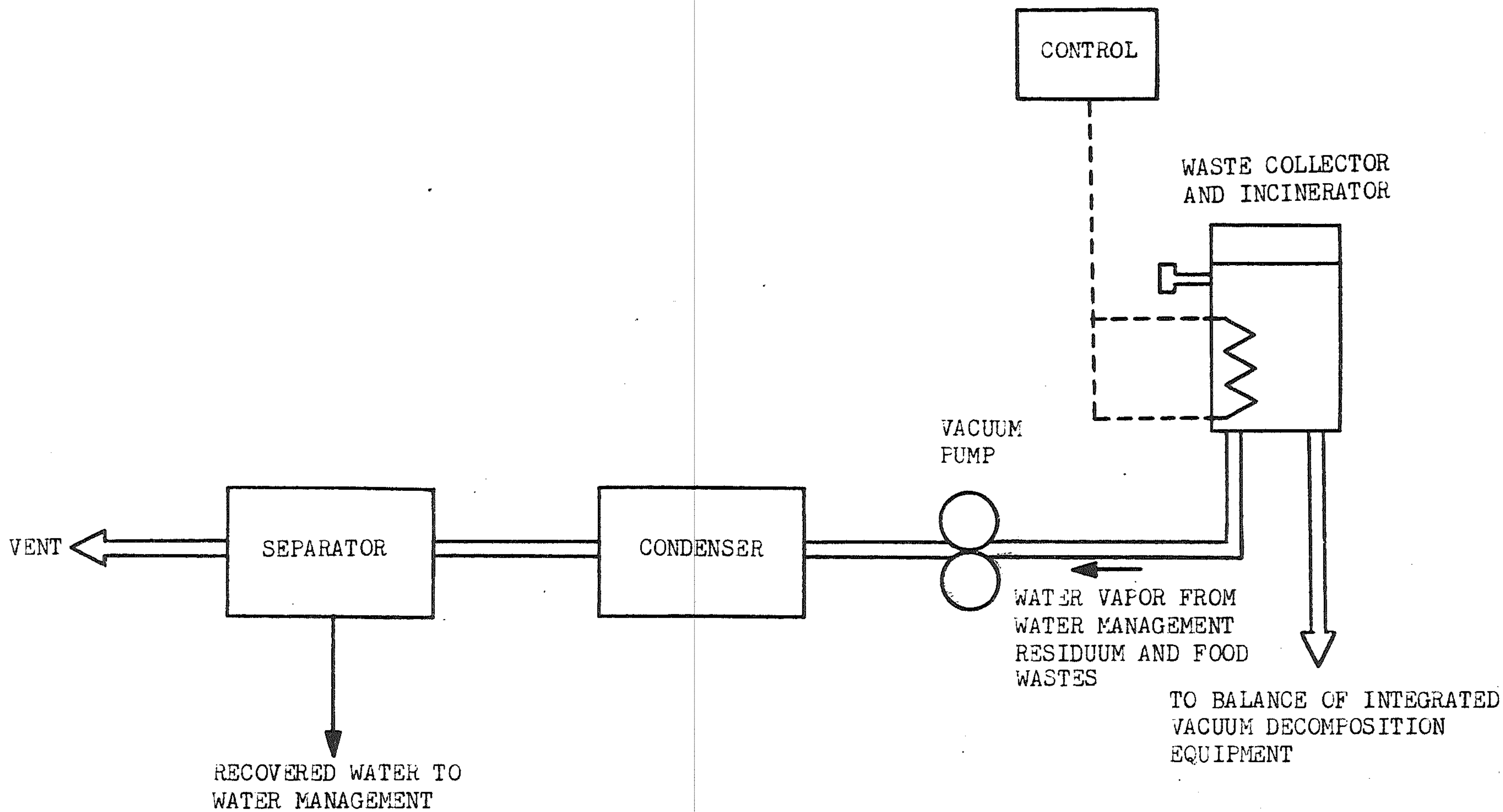

Figure 17. - Waste Water Recovery Schematic

OTHER SUBSYSTEMS

The remaining subsystems are influenced by vehicle leakage in a minor way or not at all, as discussed below.

Pressure and Composition Control

The pressure and composition control subsystem is influenced by leakage rate in that increased leakage rate requires the subsystem to handle higher gas flows. However, the weight increase is small, and the subsystem function is unchanged, so that this subsystem is essentially unchanged for higher leakage rates.

Water Electrolysis

The AILSS does not include an electrolysis subsystem. If leakage rate were such that a Sabatier concept were used for carbon dioxide reduction, however, an electrolysis subsystem would be required. Characteristics of the gas circulation electrolysis concept are especially suitable over a wide range of oxygen generation rates, and this approach would, therefore, be used for any leakage rate. Figure 18 shows the effect of required oxygen generation rate on equivalent weight of a gas circualtion electrolysis subsystem. Equivalent weight cannot be related directly to vehicle leakage without assuming a specific Sabatier concept. This consideration was included in the foregoing oxygen generation study. High failure rate becomes a problem as leakage increases, if the electrolysis unit is used for oxygen leakage makeup.

CO_2 Removal and Concentration

In theory, increasing vehicle leakage removes an increasing quantity of carbon dioxide from the cabin atmosphere, reducing the load on the carbon dioxide concentrator. However, this reduction is very small. Even at a leakage rate of 30 pounds per day, it amounts to only about three percent. Leakage of carbon dioxide from the spacecraft system represents an oxygen loss equal to about three percent of the oxygen leakage loss. Thus, increasing leakage reduces the required size of the carbon dioxide concentrator, but to a very small degree.

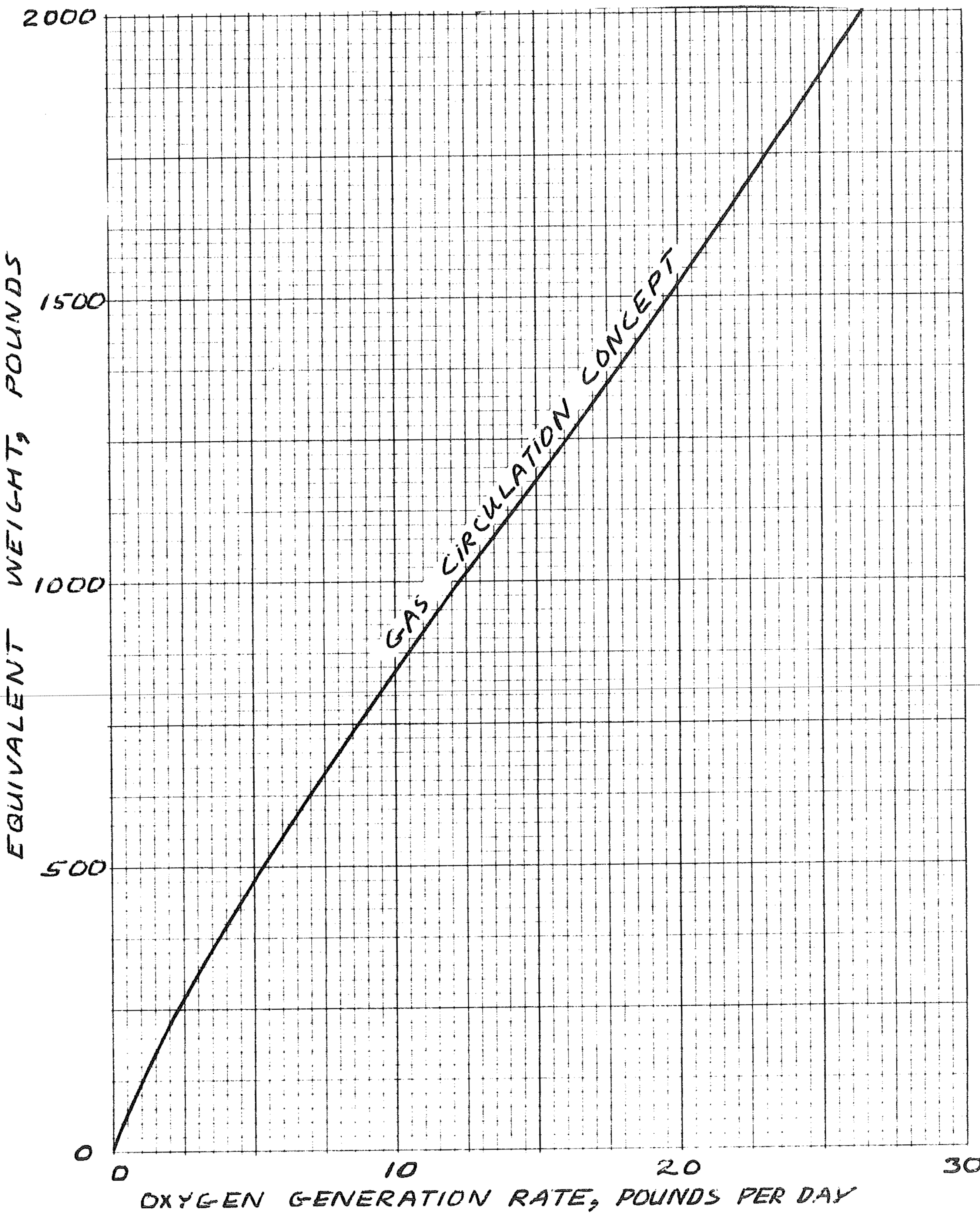

Figure 18. - Water Electrolysis

Thermal Control

The effects of leakage on this subsystem are similar to those just described for carbon dioxide. That is, increasing leakage removes an increasing quantity of water vapor from the cabin atmosphere, reducing the load on the humidity control equipment. However, this reduction is negligible. Leakage of water vapor from the spacecraft system represents an oxygen loss equal to about three percent of the oxygen leakage loss.

Crew Provisions

Leakage rate does not influence crew provisions. However, changes in the crew provisions could affect the overall oxygen-water balance, possibly reducing the affect of leakage on other subsystems. Specifically, extra water could be introduced into the total system by two concept changes. One such change would be use of "canned" or frozen food, which contains considerable water. Another change would be use of prewetted wipes for whole body cleaning. Thus, these possibilities are essentially an alternative means of storing water. However, the oxygen generation section of this report has already showed that electrolysis of stored water for leakage makeup is undesirable because of its low inherent reliability. Thus, these changes in crew provisions are an unrealistic means of oxygen supply for the AILSS, and the crew provisions subsystem would remain unchanged at higher leakage rates.

Instrumentation and Control

This subsystem is not influenced by leakage directly but depends on changes in the other subsystems. These changes have already been discussed, and the instrumentation and control equipment would change accordingly.

CONCLUSION

As a result of this study, it is concluded that the Advanced Integrated Life Support System, at a cabin pressure of 7.0 psia, should remain essentially the same for any AILSS mission with a cabin leakage rate between zero and 12 pounds per day. The only desirable change in this leakage range is modification of the waste control subsystem to recover water from the waste management residuum and food wastes at leakage rates above approximately five pounds per day. This modification of the AILSS selected vacuum decomposition concept is relatively minor.

At cabin leakage rates above 12 pounds per day, chemical (N_2H_4 or NH_3) storage of nitrogen, in combination with gaseous oxygen storage and a Sabatier-methane dump concept for oxygen generation, is very competitive on an equivalent weight basis with the AILSS selected oxygen and nitrogen gaseous storage-solid electrolyte subsystem. Because the scheduled crew time for the Sabatier concept is appreciably less than for the solid electrolyte concept, it is selected for leakage rates above 12 pounds per day.

These conclusions are illustrated in the following table:

Leakage Range at 7 psia Cabin Pressure	Oxygen Generation Selection	Oxygen Storage Selection	Nitrogen Storage Selection
0 to 12 lb/day	Solid electrolyte	High pressure gas	High pressure gas
12 lb/day and above	Sabatier-methane dump	High pressure gas	Hydrazine or ammonia decomposition

Conclusions would be different for earlier missions or for an integrated life support-propulsion system. For pre-AILSS missions where solid electrolyte would not be completely developed, the Bosch concept would be selected in the same leakage range as the solid electrolyte. That is, this study is valid for an early mission if "Bosch" is substituted for "solid electrolyte". If methane from the Sabatier-methane dump concept were used at low penalty for vehicle propulsion (minor course corrections), all versions of this Sabatier concept would tend to be more attractive. On the other hand, a technical breakthrough resulting in significant reductions in tank weight for high pressure gaseous nitrogen storage would tend to make solid electrolyte (with gaseous oxygen and nitrogen storage) more attractive.

The influence of other parameters on the impact of vehicle leakage is covered in the appendix.

APPENDIX

This appendix to the Impact of Vehicle Leakage Study Report considers the effects of varying other parameters, as well as cabin leakage, on oxygen generation, which is the subsystem most affected. The parameters to be considered are the following:

- Mission duration
- Crew size in terms of

  Metabolic oxygen consumption rate
  Metabolic carbon dioxide generation rate

- Excess water rate
- Cabin total pressure

Following a general discussion of each of these parameters, they are tied together in the form of equations resulting from a generalized materials balance.

Mission Duration

For a given leakage rate, increasing mission duration increases expendables weight but does not increase (except for spares) the basic oxygen generation equivalent weight (hardware, power equivalent, and heat rejection equivalent). Thus, at any leakage rate, a longer mission will increase the importance of the type of expendables, which comprise a larger fraction of the total equivalent weight. This tends to augment the attractiveness of some Sabatier-methane dump concepts.

Crew Size

The major influence of changing crew size on the oxygen generation subsystem is the corresponding increase in oxygen consumption rate and carbon dioxide generation rate. Increasing crew size has exactly the opposite effect as increasing mission duration, which was just described. The increased oxygen consumption is balanced by increased carbon dioxide generation, except when carbon dioxide is partially dumped. When this occurs, more expendables are required for the Sabatier concepts, which therefore become less attractive.

Excess Water

Excess water may be defined as water derived from stored food less water lost to space along with other wastes. It is generally small in magnitude and, therefore, of limited importance in the materials balance. Increasing excess water rate decreases the need for stored oxygen or oxygen-containing chemical.

Cabin Total Pressure

Variation of total cabin pressure is of special interest, because the AILSS design pressure range was 7.0 to 14.7 psia, although 7 psia was assumed to be the nominal operating pressure. Oxygen generation concept comparison at 7 psia was discussed in detail earlier in this report. Figure 19 reviews some of these results and also indicates corresponding results at a cabin pressure of 14.7 psia.

The specific conclusion implied is that the minimum leakage rate at which the Sabatier-oxygen-hydrazine concept would be selected is shifted toward a lower leakage rate. This shift occurs because at the higher total pressure, the leakage contains more nitrogen; this requires more hydrazine decomposition, which generates more hydrogen; this reduces more carbon dioxide, increasing oxygen recovery efficiency and decreasing the required weight of stored oxygen. An increase in total pressure also tends to decrease reliability of any hydrazine or ammonia concept, because the increased hydrazine decomposition rate increases the quantity of water resulting from the hydrogen separator inefficiency; this requires additional electrolysis modules, decreasing concept reliability.

General conclusions deduced from figure 18 are the following:

1. Total pressure has a significant effect on oxygen generation concept comparison results only when the oxygen-containing fluid or the nitrogen-containing fluid (but not both) contains hydrogen.

2. For a concept where only the nitrogen-containing fluid contains hydrogen, increasing total pressure at a given leakage rate decreases total equivalent weight if some carbon dioxide is dumped at the lower pressure.

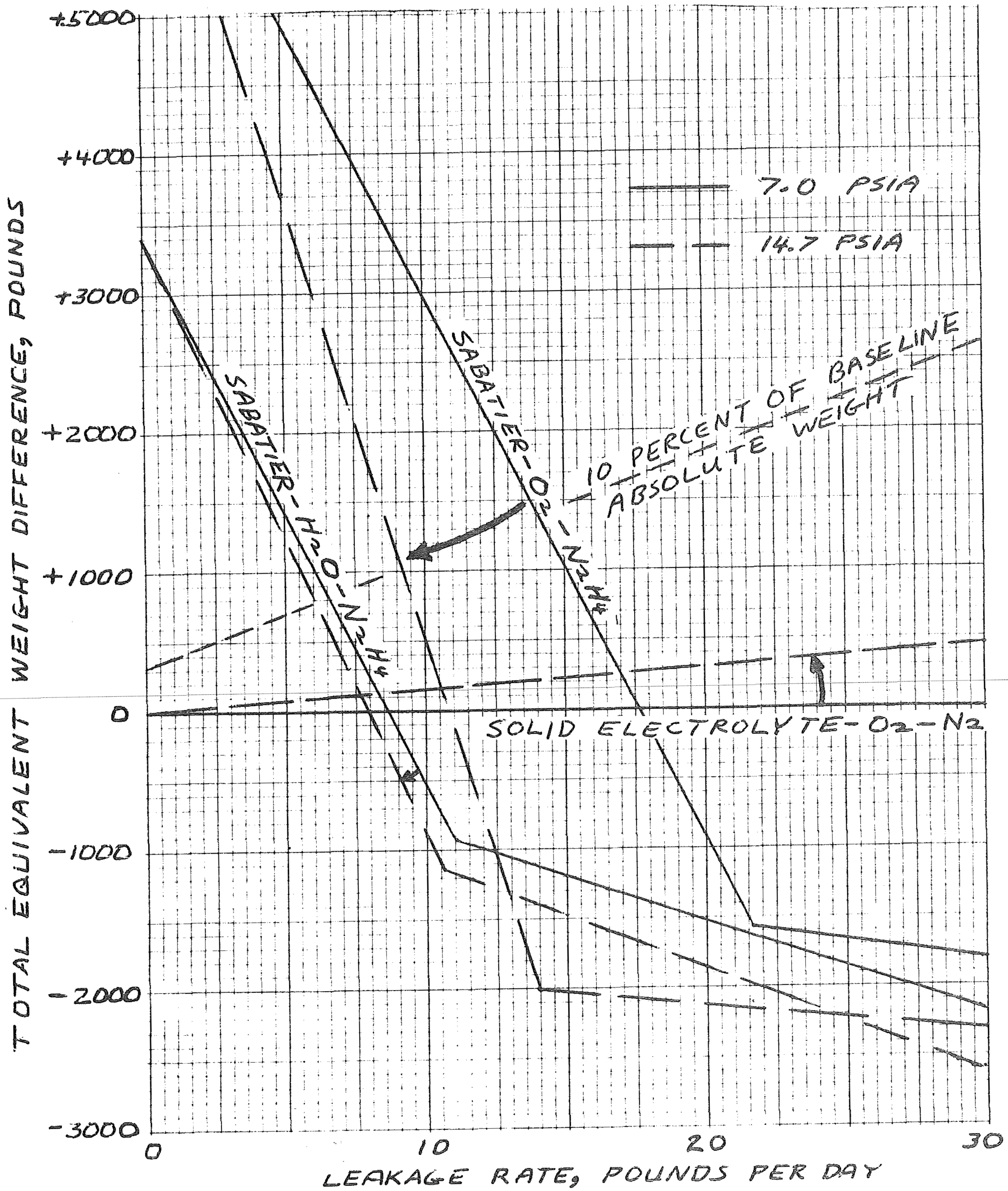

Figure 19. - Total Pressure Effects

3. For a concept where only the nitrogen-containing fluid contains hydrogen, increasing leakage rate decreases concept reliability.

4. For a concept where only the oxygen-containing fluid contains hydrogen, increasing total pressure at a given leakage rate increases total equivalent weight if some carbon dioxide is dumped at the higher pressure.

There are three basic reasons for these conclusions. First, gaseous oxygen and nitrogen storage penalties are nearly the same, so that the ratio of oxygen to nitrogen leakage generally does not have much effect. Second, when the nitrogen-containing fluid contains hydrogen, higher cabin pressure requires more nitrogen makeup, resulting in a lower stored oxygen requirement, as discussed earlier. Third, conversely, when the oxygen containing fluid only contains hydrogen, higher pressure requires less oxygen makeup, and less carbon dioxide is reduced, resulting in higher equivalent weight.

Generalized Materials Balance

Generalized materials balance equations form a basis for concept comparison for mission conditions different from those of the AILSS. The expressions shown in table 3 define expendable fluid weights only. Hardware weight and power and heat rejection equivalent weights must be added for a valid comparison of the total equivalent weights of the candidate concepts being considered.

The materials balance that led to the generalized expressions shown in table 3 is discussed here. It is convenient to make the materials balance around the equipment in which chemical reactions occur. This equipment includes the carbon dioxide reduction unit, the water electrolysis unit, and units for the decomposition of oxygen-containing and nitrogen-containing chemicals.

Using this approach, equations may be set up for Sabatier-methane dump versions as follows:

Input terms:

Excess water = W
Carbon dioxide = C
Oxygen-containing chemical = x
Nitrogen-containing chemical = $f\ (L_N)$

TABLE 3

GENERALIZED MATERIALS BALANCE EXPRESSIONS

FOR SABATIER-METHANE DUMP CONCEPTS

CONCEPT	OXYGEN-CONTAINING FLUID Pounds		NITROGEN-CONTAINING FLUID Pounds	CARBON DIOXIDE DUMP RATE Pounds/day
	$y \geq 0$	$y \leq 0$		
O_2-N_2-H_2	---------------------	$(M+L_O - 0.888W - 0.727C)\ D$	$L_N\ D$	0
O_2-N_2H_4	$(M+L_O - 1.144\ L_N - 1.776W)\ D$	$(M+L_O - 0.888W - 0.727C)\ D$	$1.144\ L_N\ D$	$C-1.22W - 1.573\ L_N$
O_2-NH_3	$(M+L_O - 1.716\ L_N - 1.776W)\ D$	$(M+L_O - 0.888W - 0.727C)\ D$	$1.216\ L_N\ D$	$C-1.22W - 1.36\ L_N$
H_2O-N_2	$[0.563\ (M+L_O) - W]\ D$	$[1.126\ (M+L_O) - W - 0.819C]\ D$	$L_N\ D$	$C-0.688\ (M+L_O)$
H_2O-N_2H_4	$[0.563\ (M+L_O) - W - 0.644\ L_N]\ D$	$[1.126\ (M+L_O) - W - 0.819C]\ D$	$1.144\ L_N\ D$	$C-0.688\ (M+L_O) - 0.787\ L_N$
H_2O-NH_3	$[0.563\ (M+L_O) - W - 0.965\ L_N]\ D$	$[1.126\ (M+L_O) - W - 0.819C]\ D$	$1.216\ L_N\ D$	$C-0.688\ (M+L_O) - 1.179\ L_N$
H_2O_2-N_2	$[0.708\ (M+L_O) - 1.258W]\ D$	$[1.062\ (M+L_O) - 0.943W - 0.772C]\ D$	$L_N\ D$	$C-0.407W - 0.459\ (M+L_O)$
H_2O_2-N_2H_4	$[0.708\ (M+L_O) - 1.258W - 0.810\ L_N]\ D$	$[1.062\ (M+L_O) - 0.943W - 0.772C]\ D$	$1.144\ L_N\ D$	$C-0.407W - 1.049L_N - 0.511\ (M+L_O)$
H_2O_2-NH_3	$[0.708\ (M+L_O) - 1.258W - 1.214\ L_N]\ D$	$[1.062\ (M+L_O) - 0.943W - 0.772C]\ D$	$1.216\ L_N\ D$	$C-0.407W - 1.573L_N - 0.511\ (M+L_O)$

y — CO_2 dump rate, lb/day
M — Total metabolic O_2 rate, lb/day
L_O — O_2 leak rate, lb/day
L_N — N_2 leak rate, lb/day
W — Excess water rate, lb/day
C — Total metabolic CO_2 rate, lb/day
D — Mission duration, days

$L_O = 8\ P_O L\ /\ (7P + P_O)$
$L_N = (P-P_O)\ L\ /\ (P + 0.143\ P_O)$
P_O — O_2 partial pressure, psia
P — Total pressure, psia
L — Total leakage rate, lb/day

Output terms:

Metabolic oxygen = M
Oxygen leakage = L_O
Nitrogen leakage = L_N
Unreacted carbon dioxide = y
Methane = 0.364 (C - y)

Some of these terms require explanation. All of the units are pounds per day. Excess water results from a water balance on the entire EC/LS system. It may be positive, negative, or zero, and it is generally equal to water in the food (including water formed by oxidation of bound hydrogen in the food) less water lost to space along with various waste materials. The input rate of the oxygen-containing chemical, x, is unknown. The input rate of the nitrogen-containing chemical, f (L_N), is proportional to the nitrogen leakage rate, with the proportionality constant equal to the atomic weight of nitrogen in the chemical divided by the molecular weight of the chemical. The oxygen leakage is given by the approximate expression: $L_O = 8 P_O L/(7P + P_O)$, where P_O is oxygen partial pressure, P is cabin total pressure, and L is total cabin leakage rate. The corresponding expression for nitrogen leakage rate is: $L_N = (P-P_O) L/(P + 0.143 P_O)$. The carbon dioxide (unreacted) output rate, y, is unknown and, therefore, the dump rate of methane formed by the reduction reaction must be expressed in terms of this unknown, 0.364 (C-y).

Performing an oxygen and hydrogen balance based on the listed input and output terms results in two equations in two unknowns, x and y. Simultaneous solution of these equations yields the materials balance expressions listed earlier.

When both the oxgyen-containing fluid and nitrogen-containing fluid contain nitrogen, the ratio of one fluid to another is somewhat flexible. This is why the N_2O_4-N_2H_4 concept, which is a good example, is not included in table 2. To illustrate the flexibility characteristic, at zero leakage metabolic oxygen may be supplied either by decomposition of N_2O_4 or by reduction of carbon dioxide with hydrogen from the decomposition of N_2H_4. It may be demonstrated, however, that minimizing N_2O_4 usage minimizes system weight. With this basis, a materials balance may be obtained. The results are as follow:

$$N_2O_4 = [1.438(M+L_O) - 1.277W - 1.045\ C]\ D \text{ pounds}$$

$$N_2H_4 = (0.727C - 0.889W)\ D \text{ pounds}$$

or $$N_2H_4 = [1.144\ L_N - 0.501\ (M+L_O) + 0.445W + 0.364C]\ D \text{ pounds},$$

whichever is greater. All carbon dioxide is reduced, regardless of leakage rate.

Expendables Storage Weight Factors

The following table shows the storage penalties used in this study. They are consistent with those used in the AILSS Final Report and reflect projected 1980 technology. The factors are in the form:

$$\frac{\text{Expendable fluid weight} + \text{tank weight}}{\text{Expendable fluid weight}}$$

Where applicable, they include a fluid decomposition penalty.

Oxygen (gaseous)	1.48
Nitrogen (gaseous)	1.59
Hydrogen (cryogenic)	2.24
Water (liquid)	1.20
Hydrazine (liquid)	1.24
Ammonia (liquid)	1.40
Hydrogen peroxide (liquid)	1.21
Nitrogen tetroxide (liquid)	1.24

These specific weights show the potential advantage of storing oxygen, nitrogen, and hydrogen in chemical form.